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WEEVILS IN BEANS AND PEAS

BEANS, peas, and cowpeas are often damaged seriously in storage and in the field by weevils. Velvet beans, soy beans, and vetches are rarely infested in this country. Bean and pea weevils not only destroy much of the Nation's food in the form of leguminous crops but are responsible for a curtailment in the acreage planted to these crops. They never attack corn and wheat.

A large percentage of the initial infestations occurs in the field, where the parent weevil lays her eggs on or in the pods. The grubs, upon hatching, burrow into the seeds by gnawing a hole no larger than a pin prick. This entrance hole is usually not observed, hence the often expressed erroneous belief that the adult weevils that eat out from the seed, leaving behind a round hole about one-sixteenth of an inch in diameter, have "developed from the germ."

The most injurious bean and pea weevils in the United States can breed generation after generation in dried seeds in storage. During the hottest summer weather one generation requires from 18 to 30 days for development. Female weevils may lay as many as 50 to 58 eggs a day, though the average total number of eggs laid by an individual during her life is about 100. Infested seeds in bulk usually heat, thus producing temperature and moisture conditions most favorable for the rapid development and vigorous breeding of weevils.

Infestations in beans and peas can be quickly and effectively stamped out by fumigation with carbon disulphid, carbon tetrachlorid, or hydrocyanic-acid gas, and by means of heat or cold storage. Weevils can be prevented from breeding in storage by mixing dust or air-slaked lime with the seeds. Concerted action by a community of growers has been known greatly to reduce weevil infestations and is recommended unreservedly for consideration in commercial bean-growing areas.

In brief: Plant weevil-free seeds, harvest as soon as possible, treat to kill weevils, and store where seeds can be protected from reinfestation by weevils spreading from infested seeds.

Preventive and remedial measures are described fully in this bulletin.

Washington, D. C. August, 1922

WEEVILS IN BEANS AND PEAS.

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SERIOUS LOSSES CAUSED BY BEAN AND PEA WEEVILS.

BEAN AND PEA WEEVILS are by no means new pests. They belong to a class of insects that cause farmers and merchants an annual loss of many millions of dollars. One Province of Canada alone suffered from the ravages of the pea weevil to the extent of over $1,000,000 in a single year. It was estimated in 1902 that the acreage in field peas in Ontario would have been 1,000,000 instead of the actual 532,639 planted, had it not been for fear of the pea weevil. Since the introduction from Europe of the broad-bean weevil into California about 1909, the pest is estimated to have reduced the acreage planted to Windsor beans 25 to 75 per cent, and in Alameda County, formerly a large producer, there is now practically no commercial acreage of these beans. The common bean weevil has been one of the chief factors in discouraging the production of field beans south of the latitude of New York, except in the higher altitudes, and is to-day one of the worst enemies of garden beans of all varieties grown in the East. Few realize that the ravages of this weevil

have forced farmers of many sections—as in the coastal regions of the Middle Atlantic States—to discontinue the production on a commercial scale of this valuable food crop and to turn their attention to other crops. The cowpea is now recognized as one of the most valuable cover crops for enriching the soil of the Southern States, and agriculturists claim that one of the drawbacks to its more general use for this purpose and for fodder is the susceptibility of cowpea seed to weevil attack. The cowpea weevils are the worst pests of cowpea seed. They are a big factor in maintaining, in years of normal production, the high cost of seed, and in the consequent curtailment of the use of this plant as a soil builder. These weevils, also, because of the rapidity with which they destroy cowpeas grown for human consumption, have caused seedsmen and merchants to view with suspicion cowpeas grown in certain sections of the South, and this attitude has had a depressing effect upon the production of cowpeas for food. Yet the South is a veritable Eldorado for the production of leguminous crops for food once weevils are controlled. It is evident, therefore, that bean and pea weevils should be charged not only with the damage they cause leguminous foods actually produced but also with the indirect losses to the country due to the reduction in the areas planted to beans, peas, and cowpeas.

FIG. 1.—Navy beans showing the emergence holes of weevils. Each of these holes is made by a weevil as it matures in the seed and leaves by cutting out a piece of the skin. All except the five small beans at the bottom have been injured by the common bean weevil. The five small beans were grown in Central America and are infested by the Mexican bean weevil. About natural size.

LOSSES OFTEN DISCOVERED TOO LATE.

Injury to edible legumes usually is observed first after the crop has been in storage for several months. Many believe that once the crop has been harvested it needs no further attention. Seeds put away at time of harvest are sometimes not examined again until the following planting season, when they are found "buggy" or "weevily" and badly damaged. The town or city gardener has proudly put away for winter consumption beans grown during the previous summer, only to find them worthless as food and full of

FIG. 2.—Field peas in bloom. Adult pea weevils begin laying their eggs on the young pods in the field. It should be remembered that the bean and pea weevils begin their attack on the seed while the crop is developing in the field. Photo by Vinal.

holes and honeycombed by grubs when later he opens the jar or sack in which they have been stored. Wonder is often expressed that seeds apparently sound when put away for the winter, and kept always well covered, should be found later injured by weevils. Because small round holes (see title page and Fig. 1) and weevils appear later in seeds seemingly perfect when harvested, a belief is current among many that bean and pea weevils develop spontaneously from the germ of the seed. That there is no foundation for such a belief is shown by the facts following.

HOW BEANS AND PEAS BECOME INFESTED.

Bean and pea weevils, like many other insect pests, pass through several marked changes in form and habits before reaching maturity. The story of development is shown in Figure 3. The weevil that is

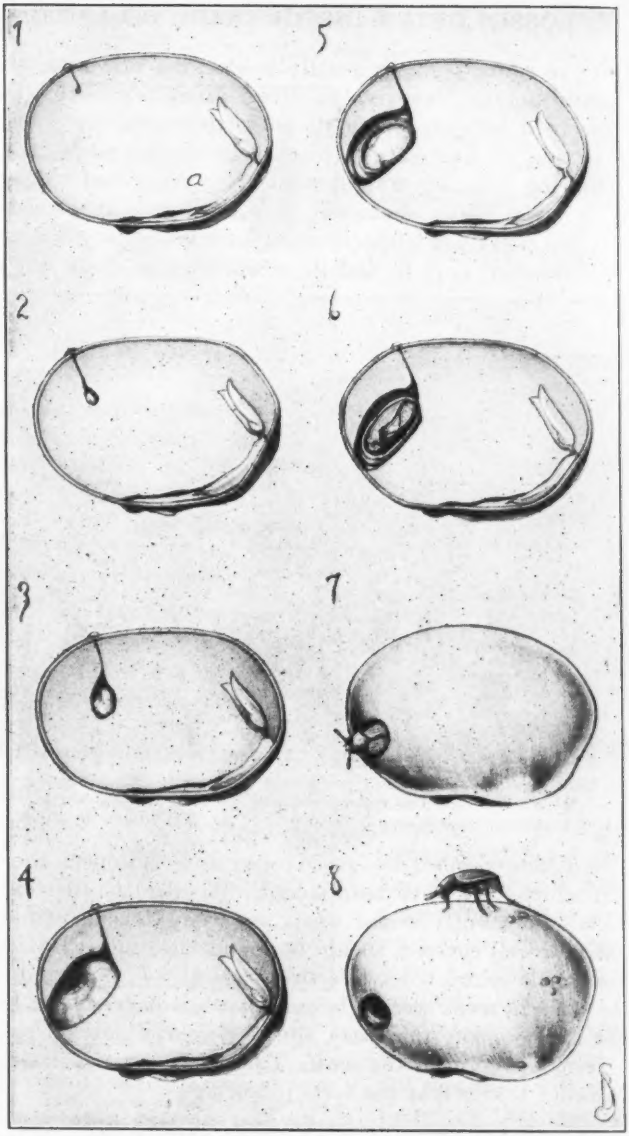

FIG. 3.—Life cycle of a bean or pea weevil: 1, Cross-section of seed showing embryo or germ at *a*, and on upper left side an eggshell and the small burrow made by the newly hatched grub from the underside of egg into the seed; 2, 3, and 4, larva or grub in different periods of growth, the larva of 4 being full grown; 5, pupa or resting stage which is intermediate between the larva and the adult; 6, side view of beetle within the pupal cocoon and ready to gnaw the round hole in the seed coat so it can crawl out of the seed; 7, beetle has eaten a circular hole in the seed coat and is crawling out; note that this emergence hole is some way from the point of entry; 8, female beetle laying eggs upon the seed.

seen crawling about among the seeds is the parent insect. Many of these fly from the storage room or house to the fields where beans and peas (Fig. 2) are growing. As the bean and pea pods develop, the mother weevil lays whitish eggs, either on the outside or within the pods. These eggs are so small that they are often not noticed, for they appear as mere white specks upon the pods. From these eggs there hatch white grubs that burrow their way through the pod into the soft developing beans or peas. Because these grubs are so very tiny, the holes through which they enter the seeds are too small to be seen unless one searches for them with a microscope. Usually beans become infested first when they are nearly or quite full grown. As seeds expand and harden in the final ripening proc-

FIG. 4.—Wagon loads of field peas brought to mill to be thrashed. Remember that the pea weevil, the broad-bean weevil, and the lentil weevil are the only weevils mentioned in this bulletin that can not breed in dried seeds in storage. For this reason any infestation by these weevils occurs only in the field while the crop is maturing; hence the weevil grubs are in the seeds at the time they are harvested, shelled, or thrashed, and any treatment at that time, if done thoroughly, will prevent the development of holes in seeds resulting from the emergence of adult weevils.

ess the holes in the skin through which the grubs entered become less and less easy to find. The wound in the skin either becomes entirely healed over or remains similar in appearance to a small pin prick.

Since beans and peas mature much faster than the weevil grubs within them, it happens that the weevil grubs are comparatively small or little developed, in many instances, when the crop is harvested (see Fig. 4) and placed in storage. Thus many seeds that appear outwardly in excellent condition in reality have weevil grubs hidden away in their interior, as shown in Figure 3.

WHERE WEEVILS IN STORAGE COME FROM.

At harvest time grubs developing from eggs laid on or in the pods in the field may have devoured very little of the seed contents, but if the seeds are stored in a warm place, or in a climate where the weather is sufficiently warm, they continue to feed and become well grown. When well grown they have eaten out of the seed contents a cavity somewhat larger than themselves and extending outward to, but not puncturing, the skin of the bean. (Fig. 5.) The grub then changes or transforms into the pupa (Fig. 10, *c;* Fig. 12, *c*) and later into the adult. This adult has a pair of sharp jaws which it uses like a pair of scissors to cut out a circular flap (see Fig. 6) in the bean skin, thus making the small round hole which is, to most gardeners, the first evidence that insects are in their beans. Through these openings the adults crawl out and by their presence in sealed jars and other containers cause much concern.

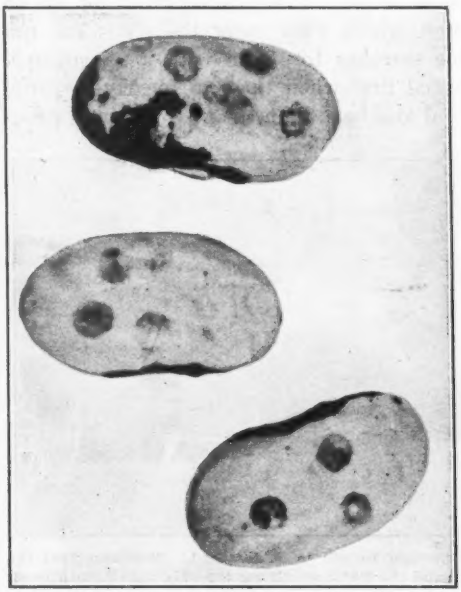

FIG. 5.—Beans in which the common bean weevil grubs have become full grown and have eaten out from the interior of the bean to, but not puncturing, the skin. As they transform to adult, each insect darkens and this dark color shows through the thin skin and makes the dark, sometimes bluish, translucent spots in beans. Such spots indicate that seeds are infested. It should be remembered that while the grubs are still growing they are white, and seeds do not indicate their presence by any such dark spots as shown above. Considerably enlarged.

DESTRUCTION CONTINUES IN STORAGE.

With the exception of the pea weevil that attacks the different varieties of peas, the broad or Windsor bean weevil, and the lentil weevil, the weevils attacking beans and cowpeas continue to produce generation after generation in dried seeds in storage. (Fig. 7.) The pea and the broad-bean weevils will die in storage and can not reproduce unless they can find growing plants in which to lay eggs. But the ordinary bean and cowpea weevils lay eggs for successive generations as readily upon dried seeds in storage as upon the growing plants

in the field. As each generation of weevils reduces the value of seeds for planting and for food, steps should be taken to kill, at harvest time, such grubs as may be in the seeds and thus prevent further losses. If this is not done the seeds become honeycombed by the feeding of generations of grubs and may be reduced to a powder. (Fig. 8.) Because bean and cowpea weevils can breed in dried seeds it is important not to store uninfested seeds near seeds that are infested, for the weevils spread rapidly and will soon infest the newer seed.

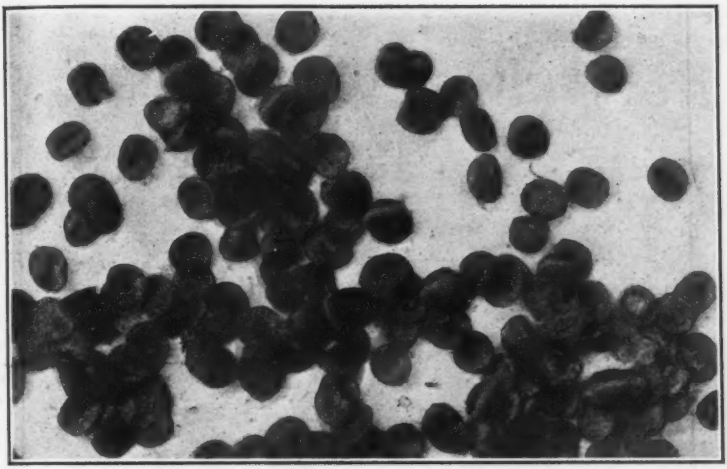

FIG. 6.—In escaping from beans, peas, or cowpeas, or any host, weevils leave behind them the small round holes familiar to all. In making these holes they use their jaws to cut around the dark spots shown in Figure 5 and then push away the circular flap of skin just as one opens a tin can of preserved fruit with a can opener. These circular bits of skin, shown above, about 4 times natural size, may be found among the seeds.

THERE ARE DIFFERENT KINDS OF WEEVILS.

Injury to leguminous crops is caused by more than one insect. Those considered in this bulletin are the pea weevil,[1] the common bean weevil,[2] the cowpea weevil,[3] the four-spotted bean weevil,[4] the broad-bean weevil,[5] the lentil weevil,[6] and the Mexican bean weevil.[7] These are all commonly found in supplies of beans, peas, cowpeas, or lentils in this country. Other species are sometimes found in imported seeds, but will not be discussed here.

[1] *Bruchus pisorum* Linnaeus.
[2] *B. obtectus* Say.
[3] *B. chinensis* Linnaeus.
[4] *B. quadrimaculatus* Fabricius.
[5] *B. ruficmanus* Boheman. [6] *B. lentis* Boheman. [7] *Spermophagus pectoralis* Say.

GENERAL DESCRIPTIVE FACTS.

The bean and pea weevils of the United States are all very small. None of them is longer than one-eighth to one-fifth of an inch.

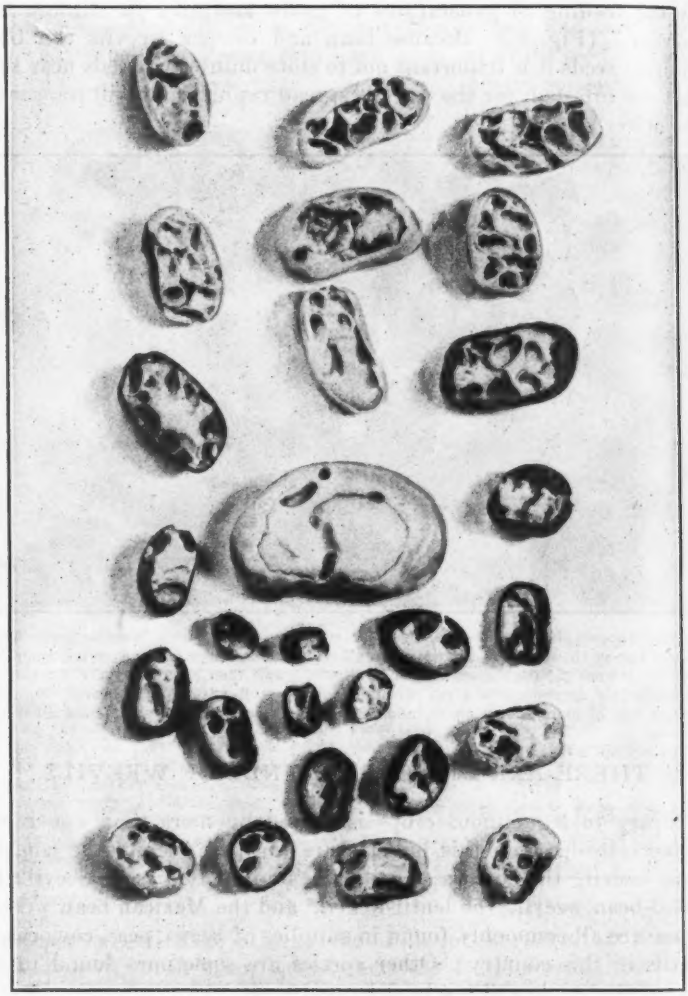

FIG. 7.—Various types of beans and cowpeas cut lengthwise to show how severely they may be damaged by bean and cowpea weevil grubs. Such beans and cowpeas are not fit for human food. Slightly enlarged.

They are dull-colored with markings of white or black. For the general shape, size, and arrangement of these markings, see Figures 10, 12, 13, 16, 19, and 20. Their eggs are from one-fiftieth to one-

twenty-fifth of an inch long, white or whitish, and appear as specks (see figs. 14 and 15) when laid on beans and cowpeas in storage.

The larvæ, or grubs, naturally are very small when first hatched and are white in color. After feeding they become somewhat maggotlike in general appearance, being nearly cylindrical, fleshy, dis-

FIG. 8.—Leguminous crops may be reduced to a powder by the continued feeding of weevil grubs. In the bottom of sacks or boxes in which weevily beans or cowpeas are held for a long time one finds quantities of dead weevils and the powdered remains of the seeds such as are shown above. About natural size.

tinctly wrinkled, more or less curved in outline, and not more than one-fourth of an inch long and usually less.

By the time the grub has become full grown it has eaten out in the seed contents a cell in which to transform to the pupa or chrysalis. Before transforming it secretes a substance which hardens into a white, filmy cell about itself, and this serves to protect the helpless

pupa while the changes to the adult are taking place. For the general shape and appearance of the grub and pupa see Figures 10, 12, and 16, *b* and *c*, and Figure 13, *c*. The pupal cells are shown in Figure 22. For the general life cycle see Figure 3.

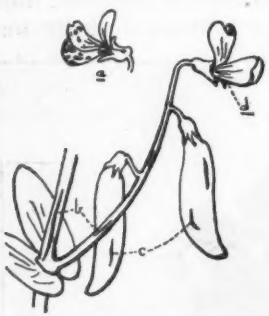

FIG. 9.—Plant of garden pea showing, at *a*, holes in blossom where pea weevil beetles have fed; at *b*, slits in stem; and at *c*, cuts in pods made by the feeding beetles. The beetle finds its favorite shelter at *d*. (Skaife.)

THE PEA WEEVIL.[8]

The pea weevil is the most serious enemy of the field or garden pea. It now occurs over almost the entire globe wherever peas are cultivated. It is scarcely known, however, in the colder countries of northern Europe and does comparatively little damage for the most part in the coldest sections of Canada and the United States. Continuous cropping of land to peas naturally leads to a constant increase in the number of pea weevils, as evidenced by the fact that garden peas grown almost anywhere in the United States, except in places in our more northern States or in high altitudes, are apt to be badly affected. This pest was causing serious damage to garden peas in Pennsylvania, New Jersey, and southern New York as early as 1748.

The pea weevil is a small grayish or brownish-gray beetle about a fifth of an inch long and marked with black and white spots as shown in Figure 10. The short line to the right of *a* in the illustration gives the actual length of the beetle. The adults appear on the vines when the peas come into bloom. They are said to feed principally on the petals of the pea flowers and on the succulent tissues of the stems and pods as shown in Figure 9. While they eat holes in the petals and gnaw out long narrow slits in the stems, they do not appear to damage the plants materially, as the damaged flowers produce normal pods and the slits in the stems soon heal over and do not cause wilting.

FIG. 10.—Pea weevil: *a*, Beetle; *b*, larva or grub; *a*, pupa. The line to the right of the adult (*a*) represents the actual length of the beetle, and the sizes of the larva and pupa are in proportion. (Chittenden.)

The adults show a strong tendency to remain dormant during the season of the year when growing peas are not available for attack.

[8] *Bruchus pisorum* Linnaeus.

Thus while certain beetles having access to pea plants lived only four or five weeks, others were found alive in dried seeds 14 months after the seeds were gathered. The female weevils lay their yellowish eggs singly upon the surface of the pods to which they attach them with a peculiar viscid secretion. The young grub upon hatching gnaws through the pod and burrows into the seed where it does practically all its feeding. While as many as six young grubs have been found in single seeds, it is seldom that more than one matures and emerges. (See Fig. 11.)

The length of time required for the eggs to hatch and for the grub or larva to mature into the adult of the next generation varies with the climate. In the District of Columbia adults have appeared as early as July 21. Others have been reared as late as the middle of August. A very considerable portion of the beetles mature and leave the seeds in the latter part of the summer in the latitude of Washington, D. C., but farther north and in higher altitudes the adults remain in the peas until the following spring, when they emerge in storage or are planted with the seed. It is in the adult stage that the weevil passes the winter, hibernating either in secluded spots in fields or buildings or in the pea seed itself. *The pea weevil has only one generation a year and can not reproduce in dried peas.*

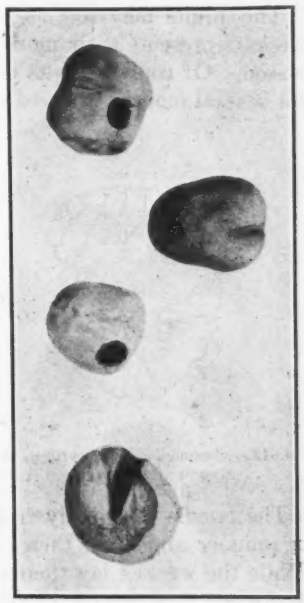

FIG. 11.—Garden peas showing exit hole of the pea weevil. Note that only one weevil develops in a single pea. One seed has been sectioned to show cavity made by grub. Enlarged.

THE COMMON BEAN WEEVIL.[9]

The common bean weevil is the most formidable enemy to the culture of beans in the United States as well as in many other countries. It occurs in nearly every State, the Territory of Hawaii, and is generally distributed throughout Mexico, Central America, and South America. It has been found in beans imported from southern Europe, Persia, India, China, Algeria, South Africa, Madeira, the Azores, and the Canary Islands. Commerce has carried it to all the larger markets of the world. So severe is its attack in the warmer sections of this country that dried beans for seed and for food are grown mostly in the more northern States and California.

[9] *Bruchus obtectus* Say.

In the coastal region of the Middle Atlantic States and farther south bean growing is made very difficult, if not rendered unprofitable, by the unmolested increase of the bean weevil.

The bean weevil is smaller than the pea weevil, being only about an eighth of an inch long, and shaped and marked as illustrated in Figure 12. The adult, or beetle, is so coated with fine hairs that it appears brownish gray or olive color. Unlike the pea weevil, the bean weevil not only can develop in growing beans in the field, but also can breed generation after generation in dried beans in storage.

The adults may live as long as nine weeks, though usually two weeks represents their more normal length of life during the active season. Of course, adults may remain alive in a dormant condition for several months in dried seeds during cold weather.

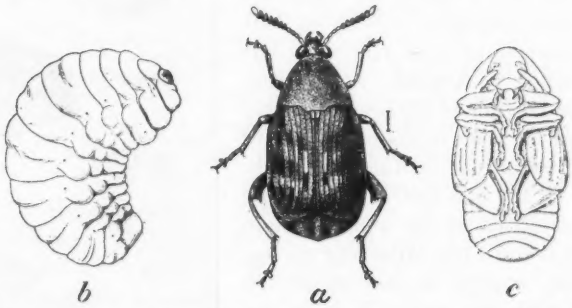

FIG. 12.—Common bean weevil: *a*, Beetle; *b*, larva or grub; *c*, pupa. The short line to right of the beetle (*a*) represents its real length. (Chittenden.)

The female weevils fly from storage or hibernating quarters early in summer and from then on may be found upon the bean plants. While the weevils lay their eggs in largest numbers through cracks in the pod that develop during the drying-out of the pod, the female has been observed to gnaw holes in green pods and to lay her eggs through such holes. Eggs are never glued to the outside of the pod as is the habit of several other species of bean and pea weevil. In storage the eggs are laid singly and loosely (i. e., unattached) among the seeds. As many as 26 eggs may be laid by a single female in one day, and a total of 85 eggs during her life. Sometimes as many as 67 eggs have been found laid through a crack in a bean pod.

As many as 28 weevil grubs have been found in a single bean. All varieties of garden beans are attacked, even lima beans being severely damaged during 1920 and 1921 in New England.

Experiments have demonstrated that the eggs of the bean weevil require from 5 days in the hottest weather to 20 days at a cooler temperature to hatch, and that the larvæ or grubs become full grown in from 11 to 42 days and the pupæ in from 5 to 18 days, according

to the temperature. It requires 21 to 80 days at least, according to the season and locality, for a generation of the bean weevil to develop. In the District of Columbia there may be as many as six generations a year. The warmer the climate the greater the number of generations and the consequent damage done by the grubs.

In a climate similar to that of the District of Columbia and adjacent parts of Maryland and Virginia adults of the first generation started in the field begin to emerge as early

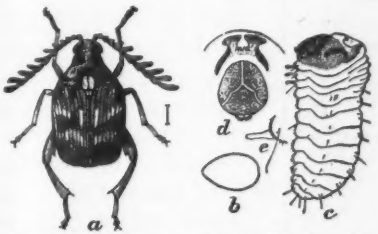

FIG. 13.—Cowpea weevil: *a*, Adult male; *b*, eggs; *c*, postembryonic larva; *d*, front view of head of same; *e*, thoracic leg of same. *a*, Much enlarged; *b–e*, more enlarged. (Chittenden.)

as October If the fall is early and the seeds are stored in a cold place no adults may emerge before the following spring. If seeds are stored in a warm place adults may emerge at any time during the winter. After emergence in storage the adult females lay eggs either on the beans or on the sides of the receptacles in which the seeds are stored.

THE COWPEA WEEVIL.[10]

The cowpea weevil (Fig. 13) is a foreign species first described from China but now widely distributed in dried seeds over the entire United States. It has been recorded from every continent and is likely to be

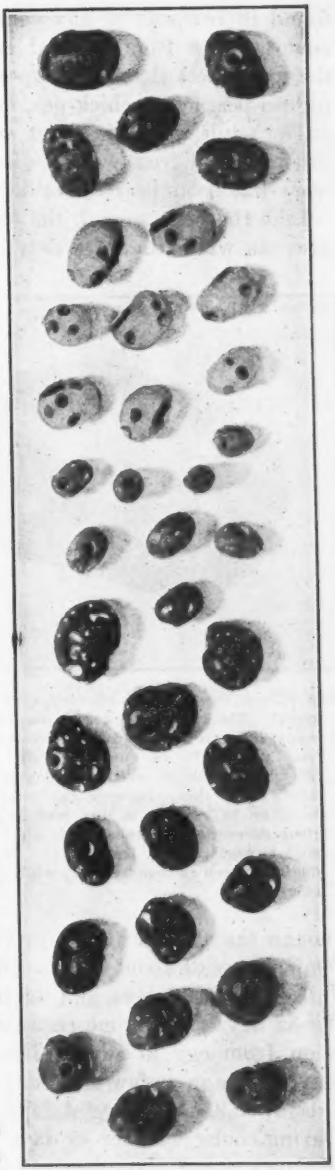

FIG. 14.—Different varieties of cowpeas showing infestation by cowpea weevil. Seed about natural size; the white specks on the seeds are the eggs of the weevil.

[10] *Bruchus chinensis* Linnaeus.

found in cowpeas in any commercial center. Although it prefers cowpeas (see Fig. 14) and is, with the four-spotted bean weevil, the worst pest that the cowpea has, it may attack the common pea, pigeon pea, lentil, chick-pea, mung bean, and common white bean.

The adult weevil is about an eighth of an inch long and may be distinguished from weevils discussed in this bulletin by the elevated ivory-like spots near the middle of the body, as shown in Figure 13.

Like the bean weevil, the cowpea weevil usually begins to infest cowpeas while they are developing in the field by laying its eggs upon the pods. It also is able to breed generation after generation in stored cowpeas and often reduces them to a powder. Because of the very warm weather of the Southern States, where the cowpea weevil is most severe in its attack upon cowpeas, the grubs mature very fast and often the adults may emerge as soon as the crop is ripe. In a fairly warm or indoor temperature six to eight generations may mature annually in a climate like that of Washington, D. C.

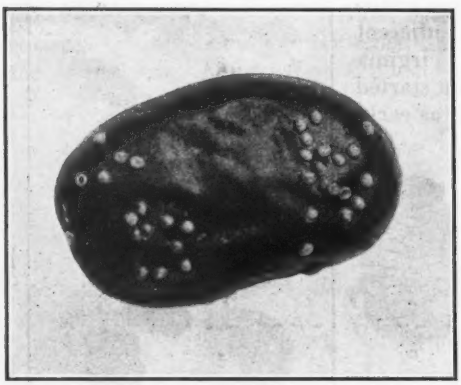

FIG. 15.—A cowpea seed showing eggs of a cowpea weevil. The eggs of bean and pea weevils vary in shape but are always small, ranging in length from one-fiftieth to one twenty-fifth of an inch. They are white or whitish, and may be laid anywhere upon the outside of the seed, as indicated here, or in cavities in the seed made by a previous generation of grubs, or on sides of containers such as burlap sacks, barrels, etc. The eggs can be distinctly seen on seeds, as tiny white specks. Much enlarged.

The beetles may live as long as 36 days, although the average life is probably about 12 days. At an average temperature of about 70° F. eggs may hatch in 8 days, larvæ become full grown in 17 days, and the pupa stage passed in 7 days; thus giving 32 days as the time required for the development of one generation from egg to adult. During very hot weather a generation may mature in as few as 18 days (egg, 3 days; larva, 12 days; pupa, 3 days) to 21 days (egg, 4 days; larva, 13 days; pupa stage, 4 days). During cooler weather 45 days (egg, 10 days; larva, 25 days; pupa, 10 days) and 60 days (egg, 10 days; larva, 40 days; pupa, 10 days) were required. Of course this period may be extended to cover three or four months during winter weather.[11]

[11] Chittenden, F. H. The Cowpea Weevil, U. S. Dept. Agr., Bur. Ent. Bul. 96, Pt. VI, 1912.

The adults live on an average 5 or 6 days during the hottest weather, to as many as 30 to 40 days during the winter months of the Gulf Coast States. Activity is likely to cease entirely at a mean temperature of 50° F., or below, when the insects will seem dead to all outward appearances and only resume activity upon the appearance of warm weather. While the immature stage may be passed in as few as 16 to 17 days, 21 days is closer to the normal time required during hot summer weather. The longest period for larval development yet recorded is 88 days, from December to March, in Texas, when the temperature ranged from 22° to 86° F. There may be from 8 to 10 generations a year in the Gulf Coast States.

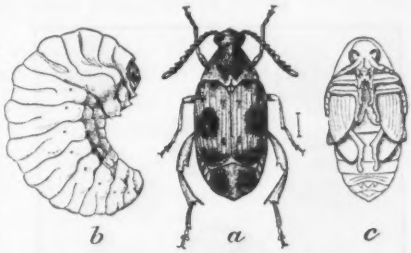

FIG. 16.—Four-spotted bean weevil: *a*, Beetle; *b*, larva or grub; *c*, pupa. Enlarged. (Chittenden.)

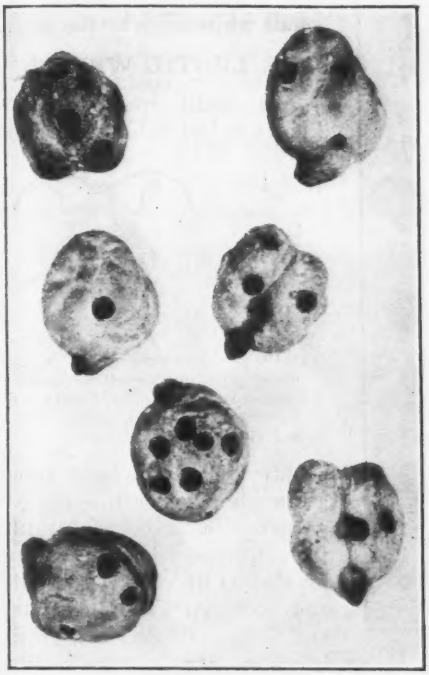

FIG. 17.—Chick-peas affected by the four-spotted bean weevil. Compare these with the two sectioned chick-peas at the bottom of Figure 22. Enlarged.

THE FOUR-SPOTTED BEAN WEEVIL.[12]

The four-spotted bean weevil somewhat resembles and is a trifle larger than the cowpea weevil, but may be distinguished from it not only by its more slender body but by the four black spots upon its wing covers as shown in figure 16.

In 1885 this species was found to be swarming on black-eyed peas from Texas exhibited at the Atlanta Cotton Exposition. Since then

[12] *Bruchus quadrimaculatus* Fab.

it has been found attacking cowpeas throughout the Southern States and as far north as Iowa and is probably present wherever cowpeas are grown. The cowpea is its favorite host food, although peas and beans are attacked (see Fig. 17). It is undoubtedly a more serious pest of cowpeas than the cowpea weevil discussed above because it seems to be more hardy. Although females may lay eggs upon the pods in the field, it breeds most prolifically in seeds in storage, gluing its small white eggs to the seeds.

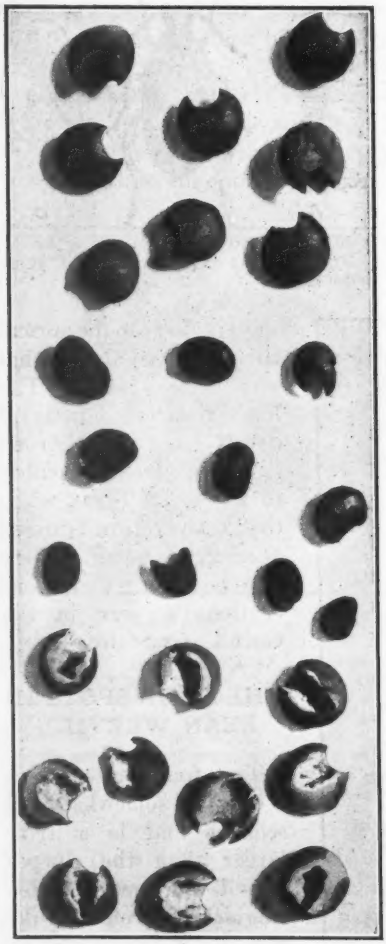

FIG. 18.—Lentils of two varieties showing injury by the lentil weevil. While only one lentil weevil matures in a single seed, it is capable of practically destroying that seed, as indicated by the sectioned seeds at the bottom of the illustration. Somewhat enlarged.

THE LENTIL WEEVIL.[13]

The lentil weevil is not known to be established in this country at the present time, although it has been found repeatedly in imported lentils from Europe. It is an enemy of the lentil crop in middle and southern Europe, Egypt, and Syria. While lentil growing is on the increase in this country, it is hoped to keep this pest from becoming established in North America.

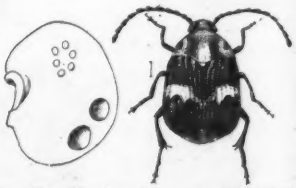

FIG. 19.—Mexican bean weevil: Adult weevil with line to left indicating actual length. Infested bean to left showing two emergence holes and six eggs. (Chittenden.)

The lentil weevil, only one of which matures in a single seed, resembles somewhat the pea weevil but is only about an eighth of an inch long. Like the pea and broad-bean weevils, it has but one generation a year. Lentils showing the

[13] *Bruchus lentis* Boheman.

emergence holes and injury caused by this weevil are illustrated in Figure 18.

THE MEXICAN BEAN WEEVIL.[14]

The Mexican bean weevil is an inhabitant of South and Central America and is frequently found at our Pacific and Atlantic ports, infesting beans imported from these countries. It attacks beans and cowpeas. It breeds continuously in dried seeds and is capable of being as injurious as the common bean weevil, as indicated by the five small beans affected by this pest, shown at the bottom of Figure 1. For the size, shape, and coloration of this insect, see Figure 19. The adult lays her eggs upon the seeds, to which they are stuck by a cement similar to that used by the cowpea weevil (Fig. 15.) While occasionally intercepted at ports of entry for many years past, this species does not appear to have become established in the United States.

FIG. 20.—Adult of the broad-bean weevil. Greatly enlarged. (Chittenden.)

THE BROAD-BEAN WEEVIL.[15]

The broad-bean weevil closely resembles the common pea weevil, being about the same size, one-fifth of an inch long, and of similar

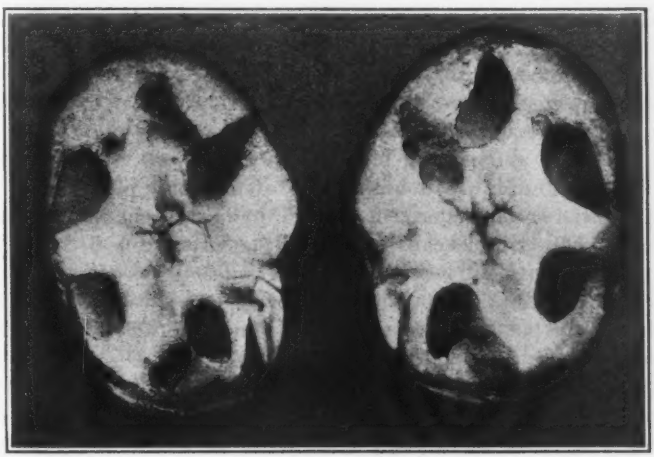

FIG. 21.—A broad, horse, or Windsor bean, grown in California, cut open to show the damage caused by grubs of the broad-bean weevil. Only one generation of this weevil occurs each year. As each cavity represents the feeding of one grub, this bean is badly affected. Considerably enlarged.

appearance. It can, however, be readily distinguished by its much narrower thorax and fainter markings, as a comparison of Figures 20 and 10 will show.

[14] *Spermophagus pectoralis* Say. [15] *Bruchus rufimanus* Boheman.

The broad-bean weevil (Fig. 20), sometimes called the European bean weevil, is common and destructive in Europe and North Africa. While it feeds upon various sorts of beans and peas, it appears to prefer the broad or Windsor beans (see Fig. 21). Although it has been found from Canada to Texas in Windsor beans imported into various parts of this country, the first discovery of its definite establishment in the United States was made in 1909 at San Luis Obispo, Calif., where it was injuring the broad or Windsor bean (*Vicia faba*) grown for stock feed.

Since then, and up to 1920, it has spread to include the coastal counties of California, from Sonoma to San Luis Obispo, besides San Benito, Santa Clara, Alameda, San Joaquin, Sacramento, Yolo, and Napa. Practically every bean entering the warehouses of New York is often more or less damaged by this pest. A single grub in its development consumes approximately 3 per cent of the bean. Sometimes as many as six weevils develop in a single bean. Beside the actual amount of seed consumed there must be considered the frass of the insect left behind in the seed and this still further reduces the value of the crop. It has been stated that of the entire broad-bean crop of California for the years 1916, 1917, and 1918, 31.21, 18.01, and 43.08 per cent, respectively, were above the 15 per cent limit of weevil infestation allowed by the Federal pure food law, and therefore could not be shipped unless hand picked. In 1916 the average percentage of infestation for the entire 1916 crop in the Halfmoon and Gilroy regions was above the 15 per cent limit, while the same is true for the Sacramento and Halfmoon districts for the 1918 crop. After a campaign of seed fumigation in San Mateo County during 1918, 1919, and 1920, it was reported that the percentage of the broad bean crop infested 15.1 per cent or more was reduced from 43 per cent in 1918, to 21 per cent in 1919, and to 17.8 in 1920. Since beans uninfested, or infested less than 15 per cent, were worth during these years from 5 to 6 cents per pound, and others only 2¼ to 3 cents, it is easy to appreciate the dollars and cents value of concerted action among growers in applying cheap, but effective, remedial measures.

The following biologic facts are taken from a report of experiments conducted at Alhambra, Calif.[16] The egg stage lasts from 9 to 18 days, the larva stage from 10 to 15 weeks, the pupa stage from 7 to 16 days, and the beetle lives from 1 to 8 months. The eggs are laid on the green bean pods in the field from the middle of March to the middle of May; the larvæ reach maturity from August to October, while the adults can be found from August to the following June. The broad-bean weevil has but one genera-

[16] Campbell, R. E. The Broad-Bean Weevil. U. S. Dept. Agr. Bul. 807. 1920.

tion each year and can not start new generations in dried seed in storage. That is, such beetles as emerge from the seeds in storage have developed exclusively from eggs laid in the field upon the green pods and can do no further injury in warehouses.

WHY WEEVILS LIMIT ACREAGE PLANTED TO CERTAIN LEGUMINOUS FOOD CROPS.

It has been pointed out already that infestation nearly always takes place in the field while the crop is maturing. With garden or Canada peas, lentils, and broad or Windsor beans infested with the pea weevil, the lentil weevil, and the broad-bean weevil, respectively, this is always the case, for these weevils never breed in dried seeds. Other species that breed in dried seeds, as well as in the field, may spread in storage to uninfested seeds and badly infest them. It is generally known that the colder the winters the shorter the growing season and the fewer the bean and pea weevils that survive the cold of winter and are ready to fly to the fields to start the infestation of the growing crop by laying eggs upon the pods. The farther south one goes the more mild the winters become, the longer the growing season, and the greater number of weevils that can live through the winter.

As far south as the District of Columbia and the adjacent tidewater country of adjoining States, therefore, overwintering weevils attack the beans and peas in large numbers and succeed in years favorable for them in laying so many eggs upon the pods that each developing bean becomes affected and often may support as many as 20 to 28 weevil grubs. Because of the long, warm falls and the length of time the plants are allowed to remain in the field after the crop has ripened, either standing in the ground or pulled and stacked, these grubs are given every opportunity to develop into adults or at least to become very well grown in an unusually large number of cases, and therefore they cause greater damage than do weevils in bean fields farther north. Thus beans grown in latitudes south of New York City, except in higher altitudes, as in the mountainous regions of the Alleghenies, become more infested than those grown north of that latitude. As weevils in beans are not killed so easily as are many other insects, and as their presence in numbers in beans is objectionable whether beans are grown for food or for planting, even when the grubs have been killed (see Fig. 22), the growing of beans on a commercial scale for dried seeds has largely been given up in our more southern latitudes. This explains the question often asked why beans and peas grown in portions of California, Michigan, New York, Washington, Oregon, or Idaho, or even in Canada, find their way into our southern markets, which one would expect should

be supplied by southern-grown beans and peas. Practically all the dried beans grown for seed and for food are grown in these northern States where the bean weevils are not able, because of climatic checks, to cause so much damage. Of course weevils do not affect the growing beans to be eaten green, as "string beans" or green shelled beans, for such beans are not, at the time of gathering, infested; or if infested, the grubs are too small to interfere with their value as food.

FIG. 22.—Beans (six upper seeds) and chick-peas (two lower seeds). The skin of the beans has been removed to reveal the cavities eaten out by the common bean weevil grubs. The grubs have been killed by fumigation and have turned black. Note the white paper-like cell or cocoon about each of the grubs. The chick-peas have been cut open to show how the larvæ of the four-spotted bean weevil can burrow to the very center of the seed. Slightly enlarged.

GERMINATION AFFECTED BY WEEVIL ATTACK.

The germination of beans, peas, and cowpeas is likely to be seriously affected by the development of weevil larvæ. If the embryo is destroyed by the larva, or if too much of the bean substance is eaten, the seeds can not grow.

Beans as badly infested as those shown in Figures 1, 7, and 23 are worthless for planting. As the young bean or pea plant depends upon the food stored in the seed to give it its first start, the destruction of any portion of the seed by weevils lessens by so much the vigor of the plant. In one experiment on record, only 50 per cent of infested beans germinated, and of these 30 per cent were so badly injured that they could not develop into normal plants. The smaller the seed, the greater proportional damage a single weevil grub can cause. One grub ruins a small cowpea seed (see Fig. 14) or a lentil (see Fig. 18), whereas it would not so seriously affect a large seed like the lima bean. The germination of broad beans infested with 1, 2, 3, and 4 or 5 broad-bean weevils was found to be reduced from a normal of 95.7 to 82.7, 72.7, 71.1, and 69.6 for new crop seed. In examining 50 garden peas infested by the pea weevil 33 were found with the embryo wholly or partially destroyed and in another case only 69 out of 275 infested peas had undamaged embryos or germs.

HEATING DUE TO INFESTATION.

It is a well-known fact that beans and peas, as well as grains, will heat if insects become sufficiently abundant in them. In bean warehouses where the seeds are stacked as shown in Figures 26 and 27, centers of weevil infestation can be detected by walking past the tiers of sacks and allowing the hand to pass over the sacks. Experience soon makes it easy to detect heating sacks. Heating seeds also produce an odor quickly detected by experienced persons when they enter a warehouse after it has been closed for a few hours.

The ability of bean and pea weevils to produce heating of the seeds is of great importance. Were it not for this ability, owners could

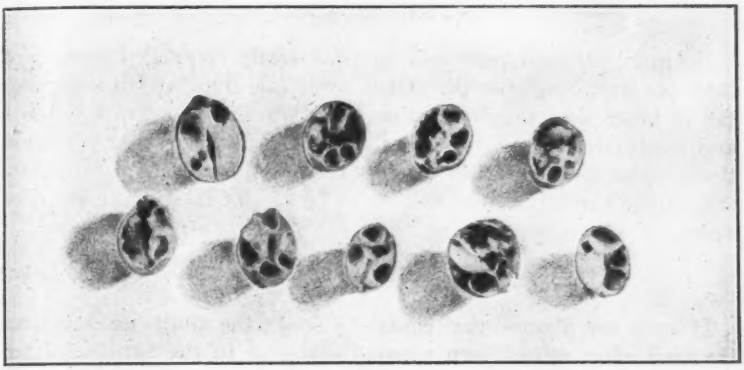

FIG. 23.—Navy beans cut crosswise to prove how the common bean weevil can ruin seeds for eating or planting. About natural size.

rest assured that if warehouses were open to outdoor temperatures below 50° F. no injury from weevils would take place. Certain weevils develop most quickly when the temperature ranges between 75° and 95° F. and egg laying is greatly stimulated by these higher temperatures. At temperatures ranging from 75° to 95° F. development of the four-spotted bean weevil has been known to be completed in as few days as 18; hence heating caused by weevil infestation, with the accompanying increase in moisture content of the seeds, may result in an outbreak of weevils at a season of the year when least expected. The temperature of a 240-pound sack of chick-peas infested by the cowpea weevil and the four-spotted bean weevil may be raised by infestation to at least 103° F. It is not uncommon in some warehouses to find a considerable number of sacks the temperature of which has been raised to over 80° or 90° F. In one instance, when the daily maximum temperatures ranged between 50° and 58° F., sacks within 2 feet of an open window registered 102° F. The temperature in the spaces between heating sacks was raised in this ware-

house from 58° F. to a minimum of 70° F. and a maximum of 78° F. At 58° F. adult weevils were too cold to migrate, but at 70° to 78° F. they were very active and were spreading from heating sacks to surrounding sacks and laying eggs upon previously uninfested seeds.

This effect of heating, due to infestation upon spread of injury from sack to sack, to say nothing of increase in infestation within the individual sacks during cold weather, should be understood by those holding beans and peas, else a genuine loss will come upon them unawares. Fumigation with hydrocyanic-acid gas (p. 29) kills the insects, reduces the temperature to normal, and stops spread. Fumigation with carbon disulphid or carbon tetrachlorid will doubtless do the same.

REMEDIES.

No group of seed pests can be more easily controlled in storage than pea and bean weevils. Once seeds are dried and housed they can be protected from destruction. Owners should watch their crop and apply treatment at the first sign of infestation. Any remedy that lessens the number of weevils present in the field has a direct effect upon the number of weevils to be fought in storage, and vice versa.

DO NOT PLANT INFESTED SEEDS.

If seeds are planted that contain weevils, the adults emerge from the seed after it has been planted and live in the field until the pods are sufficiently developed to receive the weevil eggs. They add their numbers to those in the field that have migrated from the place of seed storage. To plant peas, beans, and cowpeas containing living weevils only invites a "buggy" crop. Since the pea and broad-bean weevils can not breed in dried seeds, peas intended for planting may be held over for one year in tight paper bags so that the weevils that emerge can not live but will die before the second spring. Beans and cowpeas affected by other weevils should be treated.

PRACTICE CLEAN CULTURE.

In gathering the crop leave as little of it as possible in the field. Seeds scattered on the ground or left in scattered pods on the dried vines can carry the pest over winter and furnish a supply of weevils the following summer to offset the trouble taken to kill the weevils in storage and in seeds for planting.

HARVEST, THRASH OR SHELL, AND SACK AS SOON AS POSSIBLE.

Because some adult weevils emerge in the late summer and fall, according to the latitude, leguminous crops subject to weevil attack

should be harvested as soon as possible after reaching maturity. The seed should be thrashed or shelled at the earliest possible moment in order that the seeds may be more easily and cheaply treated to

FIG. 24.—Storing beans, peas, or cowpeas in the pod will not prevent the weevils from ruining the beans if they are already in the seeds. Neither will it prevent them from emerging, as indicated by the holes they have made in the pods shown above in making their escape from the seeds. One pod has been cut to expose the infested beans within. Work of the common bean weevil. Enlarged.

keep the weevil grubs from feeding and maturing. Storing in the pod does not confine the weevils. The grubs continue their development and transform to the adult in the unshelled as well as in the shelled seeds. Adult weevils can gnaw their way out of dried

pods, as shown by the exit holes in the pods of Figures 24 and 25. The weevils in large bulks of unthrashed or unshelled beans or peas can not be satisfactorily treated. There is only one answer to the often-asked question, "Is it better to store beans or peas in the pod or shelled?" Shell the seeds and treat them if you expect weevil injury.

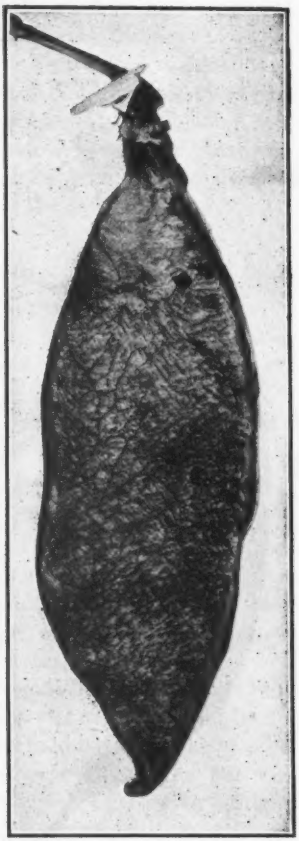

FIG. 25.—Pod of field pea showing exit hole of cowpea weevil. This pod was taken from a bale of field-pea hay grown in Florida and indicates that even field-pea hay grown only for cattle food may be instrumental in offsetting community cooperation to lessen weevil injury. Somewhat enlarged.

FUMIGATION.

Weevils may be killed in storage by fumigation with carbon disulphid, carbon tetrachlorid, or hydrocyanic-acid gas.

CARBON DISULPHID.

Fumigation with carbon disulphid (CS_2) is one of the simplest remedies for weevils. The nature and use of this fumigant is discussed in Farmers Bulletin 799, which can be had upon request from the United States Department of Agriculture. Carbon disulphid is purchased as a liquid in iron drums or tin cans and weighs about 10½ pounds per gallon at ordinary temperatures. Upon exposure to air the liquid evaporates or volatilizes, forming a foul-smelling gas that is about twice as heavy as air. Because the gas is heavier than air and evaporates more quickly if a larger surface of the liquid is exposed to the air, the liquid should be poured out into shallow pie tins or similar shallow dishes and placed upon the top of the seeds to be fumigated. Seeds will not be injured or poisoned if the liquid is sprinkled or poured directly upon them. In estimating the amount of carbon disulphid needed, the amount of cubic space in the container in which the fumigation is done should always be considered—not the amount of space occupied by the seeds.

If used according to directions, carbon disulphid will not injure the germination of thoroughly dry seeds or affect their value for

food. The disagreeable odor passes away after seeds fumigated have been aired. While carbon disulphid has become a standard fumigant and has been used for years without trouble by many individuals and firms, it is always timely to call attention to the fact that the gas is explosive and inflammable if fire is brought close to it during fumigation. By fire are meant even a lighted cigar, lighted lantern, or the spark from an electric fixture.

Seeds to be fumigated should be placed in an air-tight container. This may be a tin pail, wash boiler, barrel lined with heavy paper, galvanized-iron garbage can, or other receptacle, or a specially constructed fumigation box or room, according to the amount of seed to be fumigated. One of the simplest satisfactory containers for fumigation on a small scale is a water-tight barrel. The tighter the receptacle the better the results. Satisfactory results can not be secured if fumigation is attempted in a room full of cracks.

Carbon disulphid should be used at the rate of from 4 to 20 pounds to each 1,000 cubic feet of space to be fumigated, the amount to be used varying with the tightness of the container and the temperature. The liquid should be poured over the top of the seeds to be fumigated or poured into shallow dishes set upon the top of the seeds. It quickly vaporizes, and as the gas is heavier than air, it sinks to the bottom of the container, filling all the air spaces. Fumigation should continue from 24 to 48 hours, although most of the actual killing is done during the first 6 to 8 hours of exposure. It is always better to use too much rather than too little carbon disulphid.

Beans, cowpeas, and peas can be stored and fumigated conveniently in water-tight barrels. These should be filled to within a few inches of the top with seeds. In fumigating, pour one-half cup or more of carbon disulphid on the seeds and then cover the top of the barrel with a double thickness of heavy wrapping paper tied tight around the top, or several sacks weighted down with boards. A wooden cover is also useful in keeping in the fumes.

Fumigation with carbon disulphid to give the best results should be carried on at or above a temperature of 75° F. It is not effective at temperatures below 60° F. After fumigation the seeds should be examined occasionally and given a second or third fumigation should living weevils be found.

Carbon disulphid costs from 6 to 25 cents a pound. The following quotations were made during January, 1922, by a large producer of carbon disulphid:

55-gallon drums of 550 pounds, at 6½ cents per pound, drums $12 extra.[17]
10-gallon drums of 100 pounds, at 7½ cents per pound, drums $5 extra.[17]
5-gallon drums of 50 pounds, at 7½ cents per pound, drums $5 extra.[17]

[17] Cost of drum refunded if drum is returned f. o. b. factory in good condition within four months of shipment.

50-pound cans, at 12½ cents per pound, including can.
10-pound cans, at 17 cents per pound, including can.
5-pound cans, at 20 cents per pound, including can.
1-pound can, at 25 cents per pound, including can.

To the above price must be added transportation costs. Farmers throughout the country can purchase carbon disulphid of local drug stores, but prices under such conditions often are exorbitant. County agents, boards of trade, or other public-spirited local organizations can purchase carbon disulphid and furnish it at cost to farmers in vicinity. This has been done in certain southern towns with the result that farmers have secured carbon disulphid of excellent quality [18] at lowest price. If local firms can not supply carbon disulphid, the names of firms in a position to fill orders may be obtained upon application to the Bureau of Entomology, U. S. Department of Agriculture.

Remember, if you do not get results with carbon disulphid the trouble is (1) with the way you apply it; (2) your container is not tight; (3) your dealer has sold you poor liquid; or (4) you have fumigated when it is so cold that no one can get good results.

Remember that large business firms and many farmers use carbon disulphid successfully and that its use on farms is on the steady increase. Nothing speaks better for any control measure than its steady use by successful business men, no matter whether they are farmers or seed brokers.

CARBON TETRACHLORID.

Carbon tetrachlorid (CCl_4) is a fumigant that has been used as a substitute for carbon disulphid in fumigation work, since it has the advantage over carbon disulphid of being noninflammable. When pure, carbon tetrachlorid is a thin, transparent, colorless liquid, with a pungent, aromatic odor. Except for being noninflammable, it is similar to carbon disulphid in all essential features, from the standpoint of application. It costs from 11 to 60 cents a pound and is not more than one-half as effective as carbon disulphid. It is not likely to take the place of carbon disulphid because of its inferior killing qualities and its somewhat great cost per pound. Its great advantage is its noninflammability.

If carbon tetrachlorid can not be had from local firms the names of firms supplying this chemical may be obtained upon application to the Bureau of Entomology, U. S. Department of Agriculture.

[18] Unscrupulous dealers sometimes sell inferior lots of carbon disulphid. Dealers selling liquid containing less than 98 to 99 per cent actual CS_2 violate the Federal Insecticide Act and are liable to prosecution in Federal courts.

HYDROCYANIC-ACID GAS.

Fumigation with hydrocyanic-acid gas is recommended when large quantities of beans, peas, cowpeas, or chick-peas are found infested

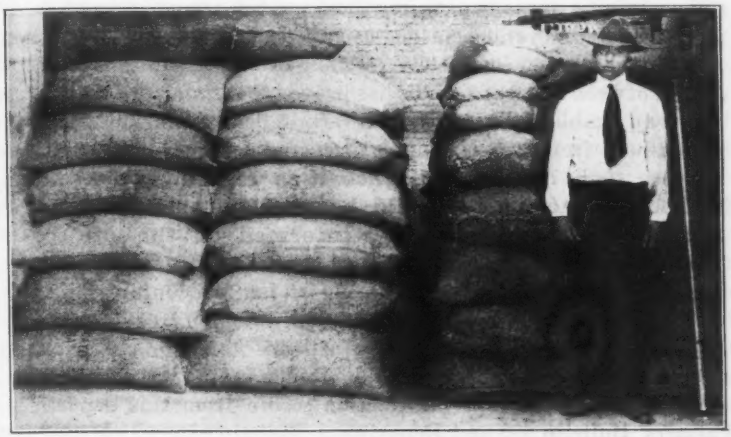

FIG. 26.—Carload lots of 240-pound sacks of chick-peas as stacked in badly infested warehouse. Samples taken throughout length of sack proved that hydrocyanic-acid gas penetrated to the very center and that infestations were killed.

FIG. 27.—Interior view of warehouse containing thirty thousand 240-pound sacks of chick-peas with a retail value of $864,000 at time of treatment. Infestations breaking out under such abnormal storage conditions were controlled by fumigation with hydrocyanic-acid gas.

with weevils. The seeds must be in sacks and so stacked that the gas can reach several sides or portions of the sacks. Chick-peas stored in

240-pound sacks, and stacked as shown in Figures 26 and 27, were almost perfectly protected by fumigation. It has been found in the fumigation of warehouses, sometimes as large as 150 by 150 by 20 feet, and containing as many as thirty thousand 240-pound sacks of chick-peas, that hydrocyanic-acid gas can be depended upon to eliminate infestations almost completely. Fumigation with this gas for the control of bean and pea weevils has proved so satisfactory that its use is now an established practice with certain firms. The dosage should be increased from 1 to 2½ pounds of cyanid for each 1,000 cubic feet of space to be fumigated. **Since it is extremely poisonous, hydrocyanic-acid gas should be used only by responsible persons who are thoroughly informed on the subject of fumigation.** As the gas is lighter than air and readily escapes, does not injure the seeds for planting or for food, injures no warehouse equipment, and is noninflammable when mixed with air in the proportions used in fumigation, it lends itself for use in almost any warehouse section if the fumigation is properly timed and supervised. For further information secure from this department Farmers' Bulletin 699 and Department Bulletin 872, which give full particulars of procedure.

HEAT.

Heat as a means of killing weevils in legumes is growing in favor. Small quantities of seed grown on the farm or in the town garden can be treated by placing them in an oven after they have been spread rather thinly in shallow pans and heating them to 120° to 145° F. for several hours. An old remedy is to dip seeds into boiling water for one minute. Holding seeds in boiling water for more than one minute will injure their value for planting purposes and exposure for even one minute has been known to affect germination. On removal they should be spread out immediately and dried rapidly.

Weevil development in large quantities of beans, peas, and cow-peas can be stopped by a process known as kiln-drying. This process consists in heating the seeds to a temperature of 120° to 145° F., or higher, while they are being passed through a machine called a drier. This treatment not only removes a portion of the moisture in the seeds but also kills all insects in them. The loss of moisture may be an item of importance if sales are made by the pound, yet investigators claim that seeds containing 20 per cent of moisture or less are not easily infested by weevils, hence excessive drying with the heat not only kills the weevils but renders seeds less susceptible to re-infestation.

The embryos of the common bean weevil are killed when exposed to 125.6° F. for 10 minutes; the newly hatched larvæ die in 7 minutes

at 131° F.; full-grown larvæ in beans die in 20 minutes at 131° F.; and pupæ die in beans when exposed for 25 minutes at 131° F. Adults are killed by a 4-minute exposure to 131° F. These data can not be relied upon when large masses of seed are to be treated. The investigator who obtained them found that 9 hours were required for the center of 2 quarts of beans inclosed in a tight paper bag to reach the surrounding temperature of 131° F. Cowpeas infested with the four-spotted bean weevil were not absolutely sterilized from an insect standpoint when exposed to 140° F. for 5 minutes, though all the weevils were killed when the seeds were exposed to this temperature for 10 minutes in an oven. These results in killing the four-spotted bean weevil were secured under conditions more favorable than those likely to occur in commercial bean establishments, hence it was recommended that seeds be exposed in commercial treatment to 146° F. for 20 to 30 minutes. Temperatures above 150° F. seemed to weaken the resulting plants, but germination took place even after the seeds had been subjected to 190° F. for 10 minutes. Commercial coffee roasters are used by certain bean brokers for the destruction of weevils by heat. Seeds have been treated by the carload in such roasters and guaranteed to remain free from injury by bean weevils at least during transit in carload lots. A list of firms that manufacture apparatus for heating seeds will be furnished upon application. As is done in kiln-drying, the seeds should be spread out in order that all may be affected quickly and uniformly by the heat. When thus spread out an exposure to 131° F. for 1 hour should be sufficient.

Heat is not recommended for the control of the broad-bean weevil in broad or Windsor beans. Exposure to temperatures ranging from 120° to 140° F. for 5 to 40 minutes did not kill this apparently more hardy insect and the higher temperatures had an injurious effect upon germination.

COLD AND COLD STORAGE.

Weevils will not feed and cause damage at low temperatures. It is not known at what temperature development ceases, but no development takes place at or below 50° F. Cowpeas can be kept free from weevils if held in storage at a temperature of 32° to 34° F. It is claimed that exposure for a season at this temperature does not affect the germinating power of the seed. Investigations conducted in this bureau and not yet completed indicate that no stage of the common bean weevil can withstand 56 days of cold storage at 31 to 32° F., although they may survive more than 66 days at 36° F. The larvæ, it appears, succumb to cold storage temperatures more readily

than do pupæ or adults.[19] The storage room should be kept as dry as possible and the seeds should be handled in sacks as in warehouses. It is interesting to note that cowpeas held for a season at 32° to 34° F. were found to lose their germinating power no sooner on removal to normal temperatures than cowpeas not thus exposed to cold. Seeds removed from cold storage to warm temperatures are likely to sweat, and if care is not taken to eliminate this surface moisture by drying or proper ventilation moldiness may result. There is some doubt as to the real need of incurring the expense of cold storage as seeds can be protected more cheaply by fumigation under storage conditions thought by the majority of seed owners to be better for the seeds.

LIME OR DUST AS PROTECTION TO SEED.

In the Southern States, where weevils cause such great injury to stored seeds, certain farmers have resorted to mixing their seed cowpeas with dry road dust or air-slaked lime. Tests prove that the storage of cowpeas with air-slaked lime at the rate of 1 part by weight of lime to 6 to 8 parts of peas is a great help in protecting seeds. The dust or lime does not necessarily kill the weevil grubs developing in the seeds if these are already in the seeds at harvest time, but it prevents adult weevils either from emerging or, if they succeed in emerging, from laying their eggs on the seeds for successive generations. The dust or lime, in other words, prevents continued breeding in storage. Either substance would probably be a nuisance if mixed with cowpeas intended for food if the seeds contained many emergence holes, as the lime or dust would work into these holes and be difficult to remove. If seeds are known to be free from weevils and are stored in tight barrels, bins, or other similar containers, a top layer of air-slaked lime about ½ to 1 inch thick, if maintained, will prevent weevils from gaining access from without and starting an infestation.

COMMUNITY EFFORT TOWARD CONTROL.

Anyone can protect beans and peas from further weevil injury after they are once dried and in storage. If loss occurs in storage, owners have only themselves to blame, for weevils can be effectively controlled at a cost very slight as compared with the value of the seeds protected and the increased value of the seeds after thorough treatment.

But no one person can prevent his beans and peas from becoming infested while they are developing in the garden or field unless he

[19] Original data (unpublished) by A. O. Larson and P. Simmons.

and his neighbors are willing to get together and pledge to treat their seeds in storage. Many adult weevils fly to fields from storage, or remain in fields harvested in a slack manner. A negligent neighbor may be the cause of much neighborhood infestation by the flying of his weevils to developing crops or into warehouses.

Community effort to reduce weevil losses can be made effective in localities where beans and peas are grown on a commercial scale. It is doubtful if concerted action can be secured in towns or cities where there are many small gardens yielding but a few seeds, for these small quantities of seed are of too little value to move their owners to action. The University of California during 1918–1920 conducted a campaign of community effort, in San Mateo County, Calif., directed against the broad-bean weevil (p. 19) and found that by working through the county agent and fumigating the crops after they were placed in storage the infestation in the field was reduced from 43 per cent in 1918 to 21 per cent in 1919 and to 17.8 per cent in 1920. The county agricultural agent has here a worth-while field for action along with his many others. To succeed, all farmers in a district should treat their seeds and destroy promptly refuse from cleaning machines.

TREATMENT DOES NOT PREVENT REINFESTATION.

Treatment of legumes subject to infestation by weevils that can breed generation after generation in storage will not keep them free from weevils if they are stored so that adult weevils can get to them and lay eggs on them. The application of remedial measures may kill all weevils in the seed at the time of treatment, but it should be remembered that no treatment has a lasting effect in preventing reinfestation from outside sources. Seeds once treated should be stored in rooms free from adult weevils, or placed in tight barrels or sacks made of closely woven material, and should be examined occasionally as a guard against subsequent infestation.

When large quantities of seeds are brought together under one roof, they usually represent the crops of many farmers whose local conditions may have varied to such an extent that one carload lot of seed may be free of infestation while the next may be slightly or heavily infested. Experimental work has proved that sacking seeds in one thickness of light-weight close-weave muslin will prevent uninfested seed from becoming infested even though there are many weevils and weevilly seeds close by. It is not practical in large seed warehouses to use sacks of light-weight muslin, yet a study in 1917–18 of conditions in large warehouses containing many carload lots of seed indicates the value of closely woven sacks. Jute sacks with

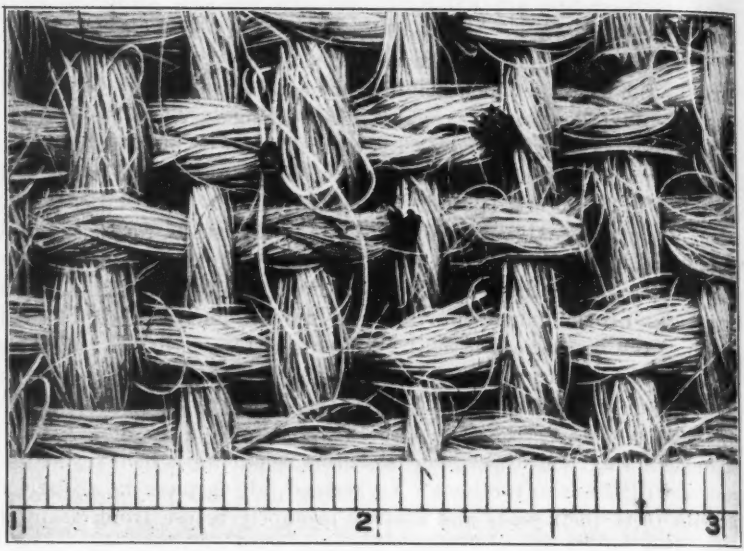

FIG. 28.—Section of jute sack having four strands to the inch. Such sacks are of no value in preventing spread of infestations from sack to sack in warehouses. The adult weevils can leave or enter such sacks at will.

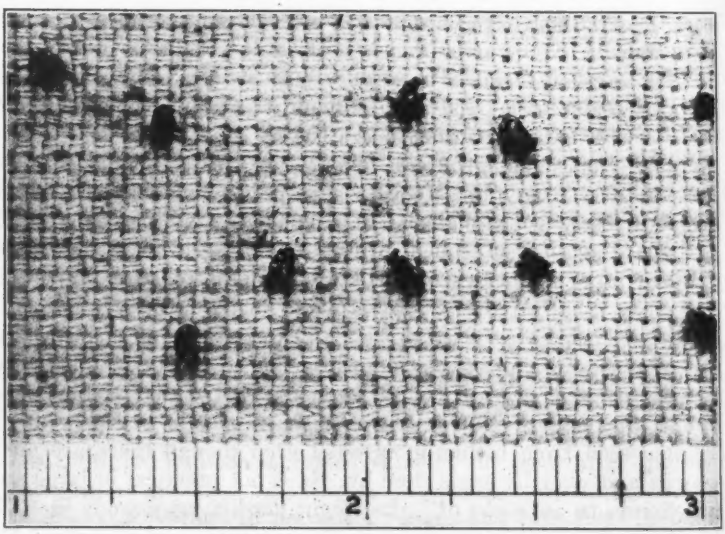

FIG. 29.—A heavy cotton close-woven sack with 24 strands to the inch. Sacks made of this material are on the market and have proved their effectiveness not only in preventing weevils from leaving the sacks but also in protecting uninfested seeds from infestation from without.

but four strands to the inch (such as shown in Fig. 28) are no protection to the seeds within the sacks and do not prevent weevils developing in the sacks from crawling out and migrating to and laying their eggs upon seeds in other sacks of similar weave. But seeds sacked in heavy cotton sacks of close weave with 24 strands to the inch are apparently perfectly protected from infestation from without (Fig. 29). Some such sacks contained badly damaged and heating seed but the infestation was held within them and prevented from spreading to adjoining sacks by the tightness of the sacks. The common bean weevil, the cowpea weevil, and the four-spotted bean weevil can eat holes in paper sacks and escape, but do not eat through cloth. There is a great deal in favor of a tight cloth sack, not only for protecting uninfested seeds from infestation from outside sources but also in preventing infestations from spreading.

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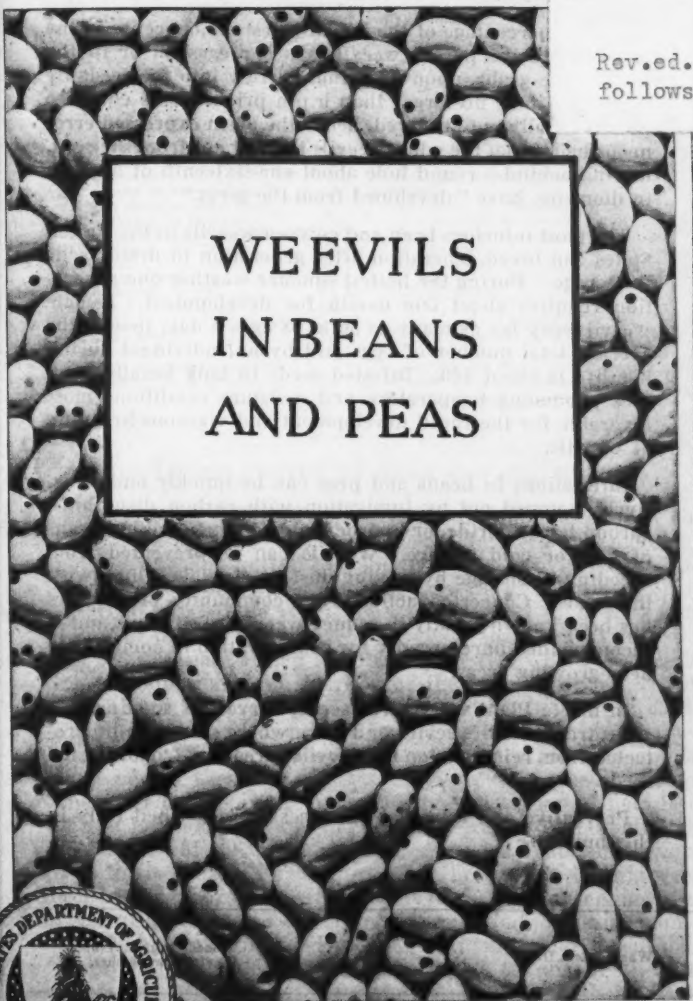
WEEVILS IN BEANS AND PEAS



XUM

BEANS, peas, and cowpeas are often damaged seriously in storage and in the field by weevils. Velvet beans, soy beans, and vetches are rarely infested in this country. Bean, pea, and cowpea weevils not only destroy much of the Nation's food in the form of leguminous crops but are responsible for a curtailment in the acreage planted to these crops. They never attack corn and wheat.

A large percentage of the initial infestations occurs in the field, where the parent weevil lays her eggs on or in the pods. The grubs, upon hatching, burrow into the seeds by gnawing a hole no larger than a pin prick. This entrance hole is usually not observed, hence the often expressed erroneous belief that the adult weevils that eat out from the seed, leaving behind a round hole about one-sixteenth of an inch in diameter, have " developed from the germ."

The most injurious bean and cowpea weevils in the United States can breed generation after generation in dried seeds in storage. During the hottest summer weather one generation requires about one month for development. Female weevils may lay as many as 50 to 58 eggs a day, though the average total number of eggs laid by an individual during her life is about 100. Infested seeds in bulk usually heat, thus producing temperature and moisture conditions most favorable for the rapid development and vigorous breeding of weevils.

Infestations in beans and peas can be quickly and effectively stamped out by fumigation with carbon disulphide, carbon tetrachloride, or hydrocyanic-acid gas, and by means of heat or cold storage. Weevils can be prevented from breeding in storage by mixing dust or air-slaked lime with the seeds. Concerted action by a community of growers has been known greatly to reduce weevil infestations and is recommended unreservedly for consideration in commercial bean-growing areas.

In brief: Plant weevil-free seeds, harvest as soon as possible, treat to kill weevils, and store where seeds can be protected from reinfestation by weevils spreading from infested seeds.

Preventive and remedial measures are described fully in this bulletin.

Washington, D. C.

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WEEVILS IN BEANS AND PEAS

By E. A. Back, *Senior Entomologist in Charge, Division of Stored-Product Insects, Bureau of Entomology*

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SERIOUS LOSSES CAUSED BY BEAN AND PEA WEEVILS

BEAN AND PEA WEEVILS are by no means new pests. They belong to a class of insects that cause farmers and merchants an annual loss of many millions of dollars. One Province of Canada alone suffered from the ravages of the pea weevil to the extent of over $1,000,000 in a single year. It was estimated in 1902 that the acreage in field peas in Ontario would have been 1,000,000 instead of the actual 532,639 planted had it not been for fear of the pea weevil. Since the introduction from Europe of the broad-bean weevil into California about 1909, the pest is estimated to have reduced the acreage planted to Windsor beans 25 to 75 per cent, and in Alameda County, formerly a large producer, there is now practically no commercial acreage of these beans. The common bean weevil has been one of the chief factors in discouraging the production of field beans south of the latitude of New York, except in the higher altitudes, and is to-day one of the worst enemies of garden beans of all varieties grown in the East. Few realize that the ravages of this weevil have forced farmers of many sections—as in the coastal regions of the Middle Atlantic States—to discontinue the production on a commercial scale of this valuable food crop and to turn their attention to other crops. The cowpea is now recognized as one of the most valuable cover crops for enriching the soil of the Southern States, and agriculturists claim that one of the drawbacks to its more gen-

eral use for this purpose and for fodder is the susceptibility of cowpea seed to weevil attack. The cowpea weevils are the worst pests of cowpea seed. They are a big factor in maintaining, in years of normal production, the high cost of seed, and in the consequent curtailment of the use of this plant as a soil builder. These weevils, also, because of the rapidity with which they destroy cowpeas grown for human consumption, have caused seedsmen and merchants to view with suspicion cowpeas grown in certain sections of the South, and this attitude has had a depressing effect upon the production of cowpeas for food. Yet the South is a veritable Eldorado for the production of leguminous crops for food once weevils are controlled. It is evident, therefore, that bean and pea weevils should be charged not only with the damage they cause leguminous foods actually produced, but also with the indirect losses to the country due to the reduction in the areas planted to beans, peas, and cowpeas.

FIG. 1.—Navy beans showing the emergence holes of weevils. Each of these holes is made by a weevil as it matures in the seed and leaves by cutting out a piece of the skin. All except the five small beans at the bottom have been injured by the common bean weevil. The five small beans were grown in Central America, and are infested by the Mexican bean weevil. About natural size

LOSSES OFTEN DISCOVERED TOO LATE

Injury to edible legumes usually is observed first after the crop has been in storage for several months. Many believe that once the crop has been harvested it needs no further attention. Seeds put away at time of harvest are sometimes not examined again until the following planting season, when they are found "buggy" or "weevily" and badly damaged. The town or city gardener has proudly put away for winter consumption beans grown during the previous summer, only to find them worthless as food and full of holes and honeycombed by grubs when later he opens the jar or sack in which they have been stored. Wonder is often expressed that seeds apparently sound when put away for the winter, and

kept always well covered, should be found later injured by weevils. Because small round holes (see title-page and fig. 1) and weevils appear later in seeds seemingly perfect when harvested, a belief is current among many that bean and pea weevils develop spontaneously from the germ of the seed. That there is no foundation for such a belief is shown by the facts following.

HOW BEANS AND PEAS BECOME INFESTED

Bean and pea weevils, like many other insect pests, pass through several marked changes in form and habits before reaching maturity. The story of development is shown in Figure 3. The weevil that is seen crawling about among the seeds is the parent insect. Many of these fly from the storage room or house to the fields where beans

FIG. 2.—Field peas in bloom. Adult pea weevils begin laying their eggs on the young pods in the field. It should be remembered that the bean and pea weevils begin their attack on the seed while the crop is developing in the field. Photo by Vinal

and peas (fig. 2) are growing. As the bean and pea pods develop, the mother weevil lays whitish eggs, either on the outside or within the pods. These eggs are so small that they are often not noticed, for they appear as mere white specks upon the pods. From these eggs there hatch white grubs that burrow their way through the pod into the soft developing beans or peas. Because these grubs are so very tiny, the holes through which they enter the seeds are too small to be seen unless one searches for them with a microscope. Usually beans become infested first when they are nearly or quite full grown. As seeds expand and harden in the final ripening process the holes in the skin through which the grubs entered become less and less easy to find. The wound in the skin either becomes entirely healed over or remains similar in appearance to a small pin prick.

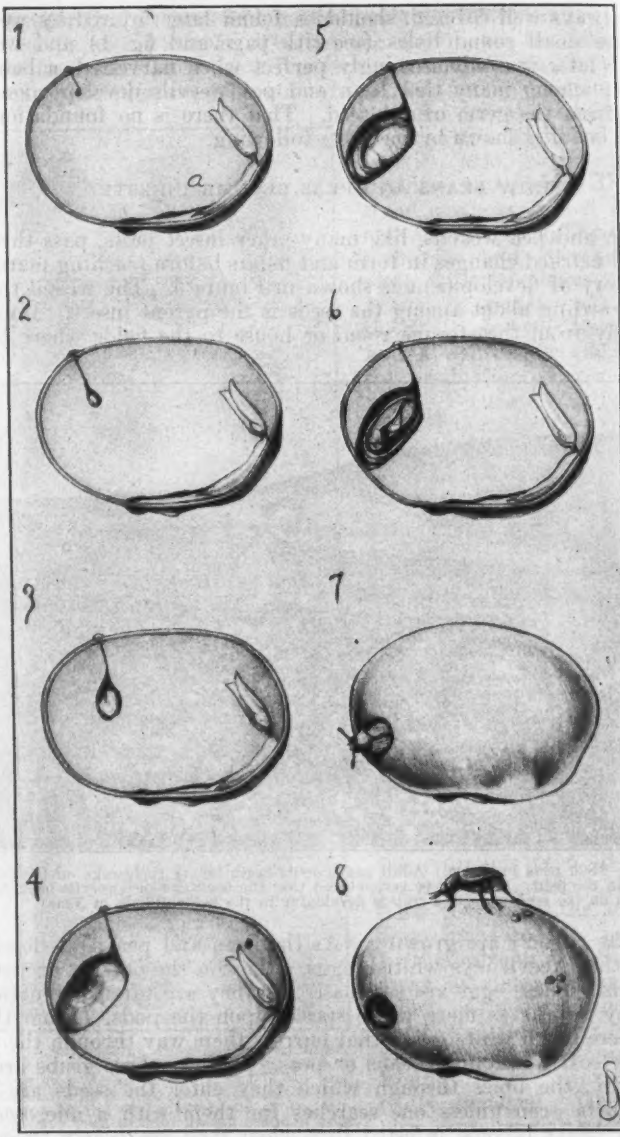

FIG. 3.—Life cycle of a cowpea weevil: 1, Cross section of seed showing embryo or germ at *a*, and on upper left side an eggshell and the small burrow made by the newly hatched grub from the underside of egg into the seed; 2, 3, and 4, larva or grub in different periods of growth, the larva of 4 being full grown; 5, pupa or resting stage, which is intermediate between the larva and the adult; 6, side view of beetle within the pupal cocoon and ready to gnaw the round hole in the seed coat so it can crawl out of the seed; 7, beetle has eaten a circular hole in the seed coat and is crawling out (note that this emergence hole is some way from the point of entry); 8, female beetle laying eggs upon the seed

Since beans and peas mature much faster than the weevil grubs within them, it happens that the weevil grubs are comparatively small or little developed, in many instances, when the crop is harvested (fig. 4) and placed in storage. Thus many seeds that appear outwardly in excellent condition in reality have weevil grubs hidden away in their interior, as shown in Figure 3.

WHERE WEEVILS IN STORAGE COME FROM

At harvest time grubs developing from eggs laid on or in the pods in the field may have devoured very little of the seed contents, but if the seeds are stored in a warm place, or in a climate where the weather is sufficiently warm, they continue to feed and become well grown. When well grown they have eaten out of the seed contents a cavity somewhat larger than themselves and extending outward to, but not puncturing, the skin of the bean. (Fig. 5.) The grub then

FIG. 4.—Wagon loads of field peas brought to mill to be threshed. Remember that the pea weevil, the broad-bean weevil, and the lentil weevil are the only weevils mentioned in this bulletin that can not breed in dried seeds in storage. For this reason any infestation by these weevils occurs only in the field while the crop is maturing; hence the weevil grubs are in the seeds at the time they are harvested, shelled, or threshed, and any treatment at that time, if done thoroughly, will prevent the development of holes in seeds resulting from the emergence of adult weevils

changes or transforms into the pupa (fig. 10, *c;* fig. 12, *c*) and later into the adult. This adult has a pair of sharp jaws which it uses like a pair of scissors to cut out a circular flap (fig. 6) in the bean skin, thus making the small round hole which is, to most gardeners, the first evidence that insects are in their beans. Through these openings the adults crawl out and by their presence in sealed jars and other containers cause much concern.

DESTRUCTION CONTINUES IN STORAGE

With the exception of the pea weevil that attacks the different varieties of peas, the broad or Windsor bean weevil, and the lentil weevil, the weevils attacking beans and cowpeas continue to produce

generation after generation in dried seeds in storage. (Fig. 7.) The pea and the broad-bean weevils will die in storage and can not reproduce unless they can find growing plants in which to lay eggs. But the ordinary bean and cowpea weevils lay eggs for successive generations as readily upon dried seeds in storage as upon the growing plants in the field. As each generation of weevils reduces the value of seeds for planting and for food, steps should be taken to kill, at harvest time, such grubs as may be in the seeds and thus prevent further losses. If this is not done the seeds become honeycombed by the feeding of generations of grubs and may be reduced to a powder. (Fig. 8.) Because bean and cowpea weevils can breed in dried seeds it is important not to store uninfested seeds near seeds that are infested, for the weevils spread rapidly and will soon infest the newer seeds.

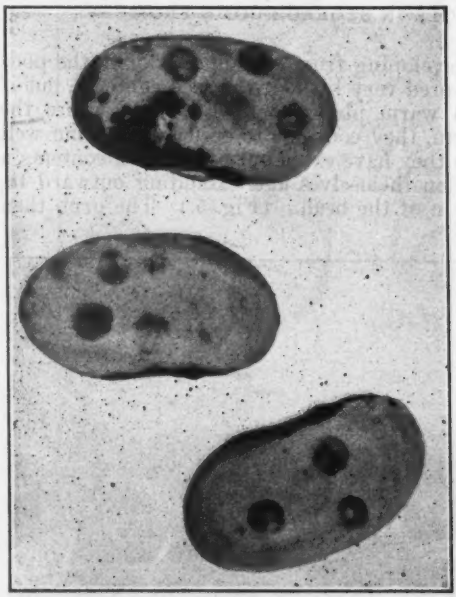

FIG. 5.—Beans in which the common bean-weevil grubs have become full grown and have eaten out from the interior of the bean to, but not puncturing, the skin. As they transform to adult, each insect darkens and this dark color shows through the thin skin and makes the dark, sometimes bluish, translucent spots in beans. Such spots indicate that seeds are infested. It should be remembered that while the grubs are still growing they are white, and seeds do not indicate their presence by any such dark spots as shown above. Three times natural size

THERE ARE DIFFERENT KINDS OF WEEVILS

Injury to leguminous crops is caused by more than one insect. Those considered in this bulletin are the pea weevil,[1] the common bean weevil,[2] the southern cowpea weevil,[3] the cowpea weevil,[4] the broad-bean weevil,[5] the lentil weevil,[6] and the Mexican bean weevil.[7] These are all found in supplies of beans, peas, cowpeas, or lentils in this country. Other bruchid weevils are sometimes found in imported seeds, but will not be discussed here.

GENERAL DESCRIPTIVE FACTS

The bean and pea weevils of the United States are all very small. None of them is longer than one-eighth to one-fifth of an inch. They are dull-colored with markings of white or black. For the

[1] *Bruchus pisorum* Linnaeus.
[2] *B. obtectus* Say.
[3] *B. quadrimaculatus* Fabricius.
[4] *B. chinensis* Linnaeus.
[5] *B. rufimanus* Boheman.
[6] *B. lentis* Boheman.
[7] *Spermophagus pectoralis* Say.

general shape, size, and arrangement of these markings, see Figures 10, 12, 13, 17, 19, and 20. Their eggs are from one-fiftieth to one-twenty-fifth of an inch long, white or whitish, and appear as specks (figs. 14 and 15) when laid on beans and cowpeas in storage.

The larvæ, or grubs, naturally are very small when first hatched and are white in color. After feeding they become somewhat maggotlike in general appearance, being nearly cylindrical, fleshy, distinctly wrinkled, more or less curved in outline, and not more than one-fourth of an inch long and usually less.

By the time the grub has become full grown it has eaten out in the seed contents a cell in which to transform to the pupa or chrysalis. Before transforming it secretes a substance which hardens into a white, filmy cell about itself, and this serves to protect the helpless

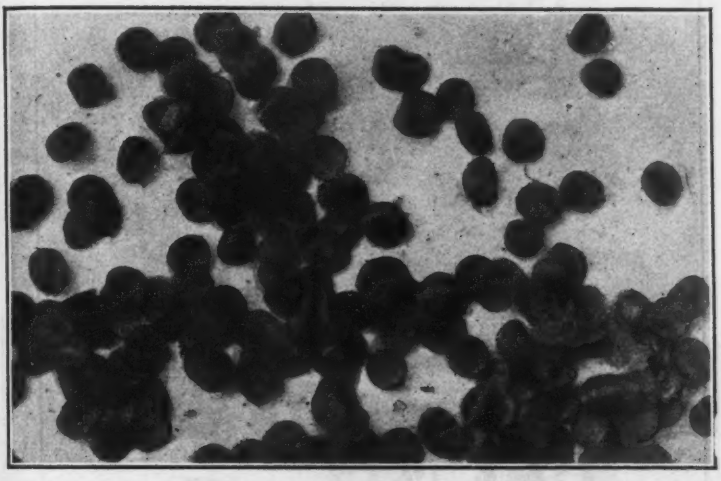

FIG. 6.—In escaping from beans, peas, or cowpeas, or any host, weevils leave behind them the small round holes familiar to all. In making these holes they use their jaws to cut around the dark spots shown in Figure 5 and then push away the circular flap of skin just as one opens a tin can of preserved fruit with a can opener. These circular bits of skin, shown above, about four times natural size, may be found among the seeds

pupa while the changes to the adult are taking place. For the general shape and appearance of the grub and pupa see Figures 10, 12, and 13, *b* and *c*, and Figure 17, *c*. The pupal cells are shown in Figure 22. For the general life cycle see Figure 3.

THE PEA WEEVIL[8]

The pea weevil is the most serious enemy of the field or garden pea. It now occurs over almost the entire globe wherever peas are cultivated. It is scarcely known, however, in the colder countries of northern Europe and does comparatively little damage for the most

[8] *Bruchus pisorum* Linnæus.

part in the coldest sections of Canada and the United States. Continuous cropping of land to peas naturally leads to a constant increase in the number of pea weevils, as evidenced by the fact that

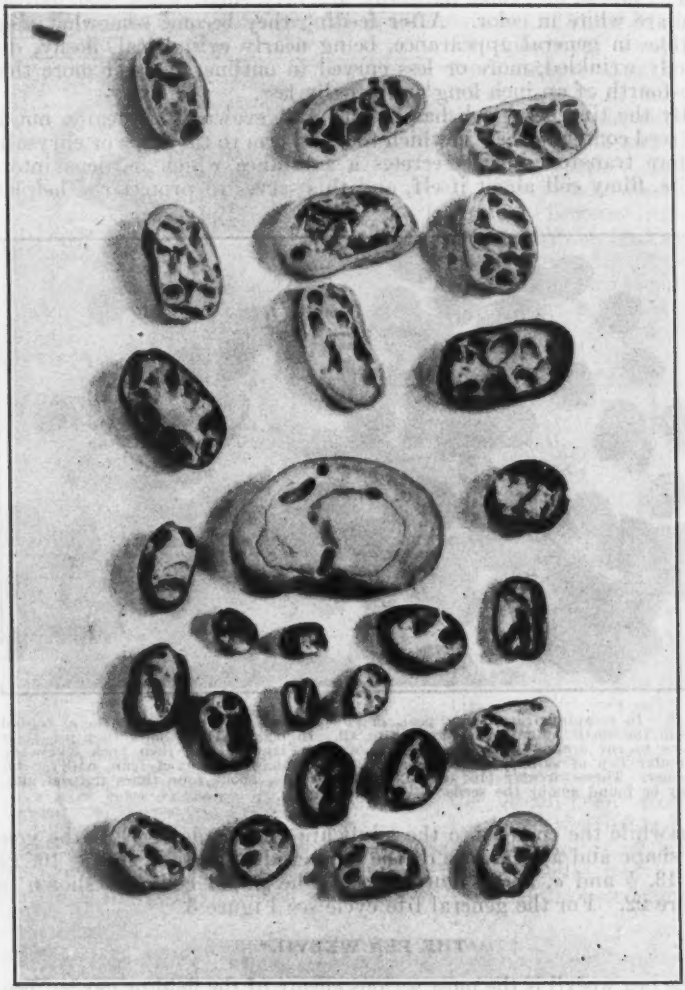

FIG. 7.—Various types of beans and cowpeas cut lengthwise to show how severely they may be damaged by bean and cowpea weevil grubs. Such beans and cowpeas are not fit for human food. Slightly enlarged

garden peas grown almost anywhere in the United States, except in places in our most northern States or in high altitudes, are apt to be badly affected. This pest was causing serious damage to

garden peas in Pennsylvania, New Jersey, and southern New York as early as 1748.

The pea weevil is a small grayish or brownish-gray beetle about a fifth of an inch long and marked with black and white spots as shown in Figure 10. The short line to the right of *a* in the illus-

FIG. 8.—Leguminous crops may be reduced to a powder by the continued feeding of weevil grubs. In the bottom of sacks or boxes in which weevily beans or cowpeas are held for a long time one finds quantities of dead weevils and the powdered remains of the seeds such as are shown above. About natural size

tration gives the actual length of the beetle. The adults appear on the vines when the peas come into bloom. They are said to feed principally on the petals of the pea flowers and on the succulent tissues of the stems and pods as shown in Figure 9. While they eat holes in the petals and gnaw out long narrow slits in the stems, they do not appear to damage the plants materially, as the damaged

flowers produce normal pods and the slits in the stems soon heal over and do not cause wilting.

The adults show a strong tendency to remain dormant during the season of the year when growing peas are not available for attack. Thus while certain beetles having access to pea plants lived only four or five weeks, others were found alive in dried seeds 14 months after the seeds were gathered. The female weevils lay their yellowish eggs singly upon the surface of the pods to which they attach them with a peculiar viscid secretion. The young grub upon hatching gnaws through the pod and burrows into the seed, where it does practically all its feeding. While as many as six young grubs have been found in single seeds, it is seldom that more than one matures and emerges. (Fig. 11.)

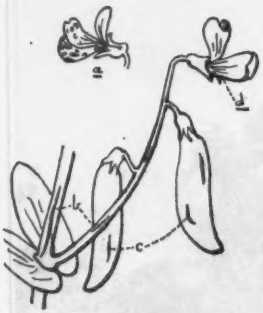

FIG. 9.—Plant of garden pea showing, at *a*, holes in blossom where pea weevil beetles have fed; at *b*, slits in stem; and at *c*, cuts in pods made by the feeding beetles. The beetle finds its favorite shelter at *d*. (Skaife)

The length of time required for the eggs to hatch and for the grub or larva to mature into the adult of the next generation varies with the climate. In the District of Columbia adults have appeared as early as July 21. Others have been reared as late as the middle of August. A very considerable portion of the beetles mature and leave the seeds in the latter part of the summer in the latitude of Washington, D. C., but farther north and in higher altitudes the adults remain in the peas until the following spring, when they emerge in storage or are planted with the seed. It is in the adult stage that the weevil passes the winter, hibernating either in secluded spots in fields or buildings or in the pea seed itself. The pea weevil has only one generation a year and can not reproduce in dried peas.

THE COMMON BEAN WEEVIL[9]

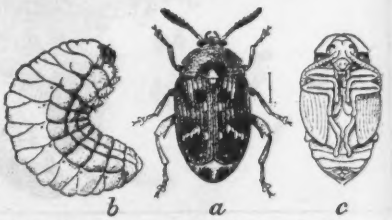

FIG. 10.—Pea weevil: *a*, Beetle; *b*, larva or grub; *c*, pupa. The line to the right of the adult (*a*) represents the actual length of the beetle, and the sizes of the larva and pupa are in proportion. (Chittenden)

The common bean weevil is the most formidable enemy to the culture of beans in the United States as well as in many other countries. It occurs in nearly every State and the Territory of Hawaii, and is generally distributed throughout Mexico, Central America, and South America. It has been found in beans imported from southern Europe, Persia, India, China, Algeria, South Africa, Madeira, the Azores, and the Canary Islands. Commerce has carried it to all the larger markets of the world. So severe is its attack in the warmer sections of this country that dried beans for seed and for food are grown mostly in the more northern States and California.

[9] *Bruchus obtectus* Say.

In the coastal region of the Middle Atlantic States and farther south bean growing is made very difficult, if not rendered unprofitable, by the unmolested increase of the bean weevil.

The bean weevil is smaller than the pea weevil, being only about an eighth of an inch long, and shaped and marked as illustrated in Figure 12. The adult, or beetle, is so coated with fine hairs that it appears brownish gray or olive color. Unlike the pea weevil, the bean weevil not only can develop in growing beans in the field, but also can breed generation after generation in dried beans in storage.

The adults may live as long as nine weeks, though usually two weeks represents their more normal length of life during the active season. Of course, adults may remain alive in a dormant condition for several months in dried seeds during cold weather.

The female weevils may fly from storage quarters early in summer and from then on may be found upon the bean plants. While the weevils lay their eggs in largest numbers through cracks in the pod that develop during the drying out of the pod, the female has been observed to gnaw holes in green pods and to lay her eggs through such holes. Eggs are never glued to the outside of the pod as is the habit of several other species of bean and pea weevil. In storage the eggs are laid singly

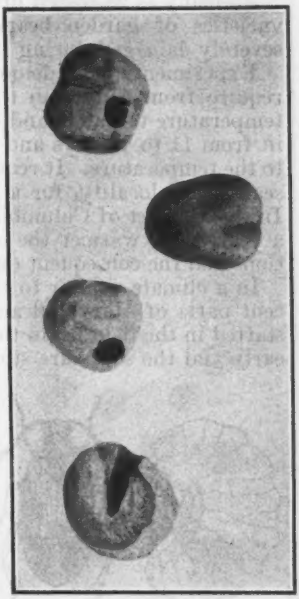

FIG. 11.—Garden peas showing exit hole of the pea weevil. Note that only one weevil develops in a single pea. One seed has been sectioned to show cavity made by grub. Twice natural size

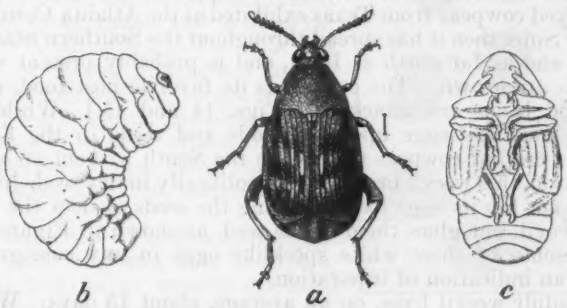

FIG. 12.—Common bean weevil: *a*, Beetle; *b*, larva or grub; *c*, pupa. The short line to right of the beetle (*a*) represents its real length. (Chittenden)

and loosely (i. e., unattached) among the seeds. As many as 59 eggs may be laid by a single female in one day, and a total of 209 eggs

during her life.[10] Sometimes as many as 67 eggs have been found laid through a crack in a bean pod.

As many as 28 weevil grubs have been found in a single bean. All varieties of garden beans are attacked, even Lima beans being severely damaged during 1920 and 1921 in New England.

Experiments have demonstrated that the eggs of the bean weevil require from 5 days in the hottest weather to 20 days at a cooler temperature to hatch, and that the larvæ or grubs become full grown in from 11 to 42 days and the pupæ in from 5 to 18 days, according to the temperature. It requires 21 to 80 days at least, according to the season and locality, for a generation of the bean weevil to develop. In the District of Columbia there may be as many as six generations a year. The warmer the climate the greater the number of generations and the consequent damage done by the grubs.

In a climate similar to that of the District of Columbia and adjacent parts of Maryland and Virginia, adults of the first generation started in the field begin to emerge as early as October. If the fall is early and the seeds are stored in a cold place no adults may emerge before the following spring. If seeds are stored in a warm place, adults may emerge at any time during the winter. After emergence in storage the adult females lay eggs either on the beans or on the sides of the receptacles in which the seeds are stored.

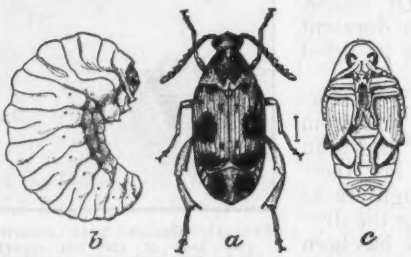

FIG. 13.—Southern cowpea weevil: *a*, Beetle; *b*, larva or grub; *c*, pupa. Six times natural size. (Chittenden)

SOUTHERN COWPEA WEEVIL[11]

The southern cowpea weevil is a major pest of cowpeas in the United States. The female is about one-eighth of an inch long and is distinguished by four black spots upon the wing covers as shown in Figure 13. In 1885 this species was found swarming on black-eyed cowpeas from Texas exhibited at the Atlanta Cotton Exposition. Since then it has spread throughout the Southern States, California, and as far north as Iowa, and is probably present wherever cowpeas are grown. The cowpea is its favorite host food, although peas and beans are attacked. (Figs. 14 and 15.) While female weevils may lay eggs upon the pods and seeds in the field, and hardly a crop of cowpeas matures in the South without an abundant infestation, this weevil breeds most prolifically in dry seeds in storage. It does not lay its eggs loosely among the seeds as does the common bean weevil, but glues them to the seed, as shown in Figure 15, and the presence of these white specklike eggs in any consignment is always an indication of infestation.

The adult weevil lives, on an average, about 15 days. While the average number of eggs laid per female in certain experiments was 82, as many as 196 eggs were laid by one female. Usually the largest

[10] Records of A. O. Larson and C. K. Fisher. [11] *Bruchus quadrimaculatus* Fabricius.

numbers of eggs are laid during the first few days of adult life. One female weevil laid 22, 15, 15, 14, 6, 13, 2, 11, 6, 0, 0, and 2 eggs, respectively, on the first 12 days after leaving the seed in which she developed. Death soon follows the completion of egg laying. Eggs hatch in from 4 to 6 days during warm summer weather. During the cold winter weather in Texas eggs require from 25 to 37 days for development. The percentage of eggs that hatch in winter is very small while that in summer is very high. The length of the larval stage varies from 9 days to more than 8 months. During warm summer weather from 17 to 22 days is usually required. Larvae emerging from eggs laid late in the fall require long periods for development and pass the winter as dormant grubs within seeds in cold warehouses. Taking the egg, larval, and pupal stages into consideration, it is safe to say that development requires from 30 to 48 days during warm weather.

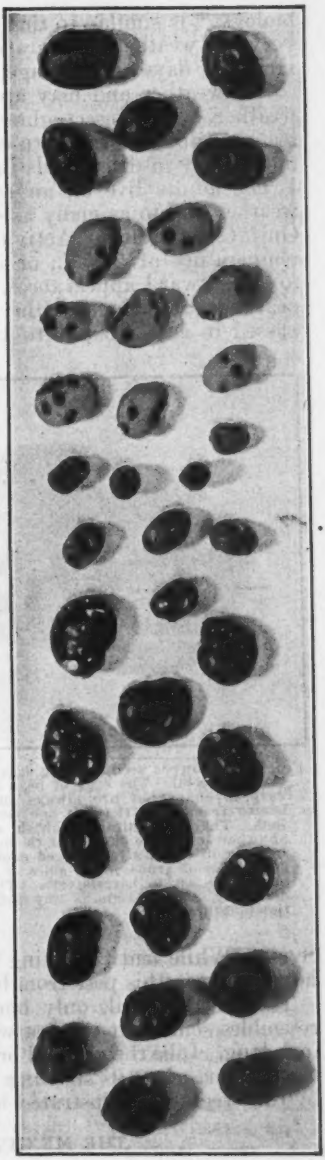

FIG. 14.—Different varieties of cowpeas showing infestation by southern cowpea weevil. Seed about natural size; the white specks on the seeds are the eggs of the weevil

THE COWPEA WEEVIL [12]

The cowpea weevil (fig. 17) is a foreign species first described from China. It has been reported from every continent and is likely to be found in any commercial center. From 1898 to 1911 it was known to be well distributed and often abundant throughout the Gulf Coast States and even as far north as Washington, D. C. It is now a pest of minor importance in the United States, where it has not been observed for some years. Although it prefers cowpeas, it may attack the common pea, pigeon pea, lentil, chick pea, mung bean, and the common white bean.

The adult weevil is about an eighth of an inch long and may be distinguished from other weevils discussed in this bulletin by the elevated ivory-like spots near the middle of the body, as shown in Figure 17. Its

[12] *Bruchus chinensis* Linnaeus.

biology [13] is similar to that of the southern cowpea weevil. During very hot weather a generation may mature in 21 days (egg, 4 days; larva, 13 days; pupa stage, 4 days). This period is lengthened by cooler weather and may approximate 3 or 4 months during winter weather. This insect glues its whitish eggs to the surface of the seeds, as does the southern cowpea weevil, and is capable of breeding indefinitely in dried seeds in storage.

The adults live on an average 5 or 6 days during the hottest weather and to as many as 40 days during the winter months in the Gulf Coast States. Activity is likely to cease entirely at a mean temperature of 50° F., or below, when the insects will seem dead to all outward appearances, and only resume activity upon the appearance of warm weather. While the immature stage may be passed in as few as 16 to 17 days, 21 days is closer to the normal time required during hot summer weather. The longest period for larval development yet recorded is 88 days, from December to March, in Texas, when the temperature ranged from 22° to 86°. There may be from 8 to 10 generations a year in the Gulf Coast States.

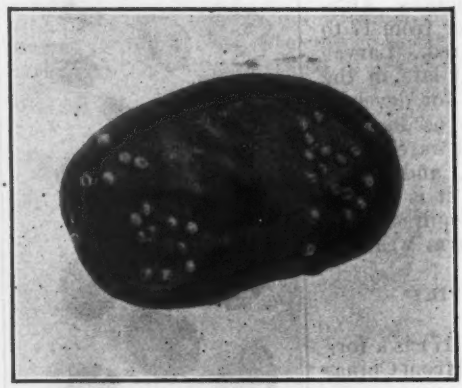

FIG. 15.—A cowpea seed showing eggs of the southern cowpea weevil. The eggs of bean and pea weevils vary in shape but are always small, ranging in length from one-fiftieth to one twenty-fifth of an inch. They are white or whitish, and may be laid anywhere upon the outside of the seed, as indicated here, or in cavities in the seed made by a previous generation of grubs, or on sides of containers such as burlap sacks, barrels, etc. The eggs can be distinctly seen on seeds, as tiny white specks. Five times natural size

THE LENTIL WEEVIL [14]

The lentil weevil is not known to be established in this country at the present time, although it has been found repeatedly in imported lentils from Europe. It is an enemy of the lentil crop in middle and southern Europe, Egypt, and Syria. While lentil growing is on the increase in this country, it is hoped to keep this pest from becoming established in North America.

The lentil weevil, only one of which matures in a single seed, resembles somewhat the pea weevil but is only about an eighth of an inch long. Like the pea and broad-bean weevils, it has but one generation a year. Lentils showing the emergence holes and injury caused by this weevil are illustrated in Figure 18.

THE MEXICAN BEAN WEEVIL [15]

The Mexican bean weevil is an inhabitant of South and Central America and is occasionally found at our Pacific and Atlantic ports,

[13] CHITTENDEN, F. H. THE COWPEA WEEVIL. U. S. Dept. Agr., Bur. Ent. Bul. 96, Pt. VI, 12 pp., illus., 1912.

[14] *Bruchus lentis* Boheman.

[15] *Spermophagus pectoralis* Say.

infesting beans imported from these countries. It attacks beans and cowpeas. It breeds continuously in dried seeds and is capable of being as injurious as the common bean weevil, as indicated by the five small beans affected by this pest, shown at the bottom of Figure 1. For the size, shape, and coloration of this insect, see Figure 19. The adult lays her eggs upon the seeds, to which they are stuck by a cement similar to that used by the southern cowpea weevil. (Fig. 15.) While occasionally intercepted at ports of entry for many years past, this species does not appear to have become established in the United States.

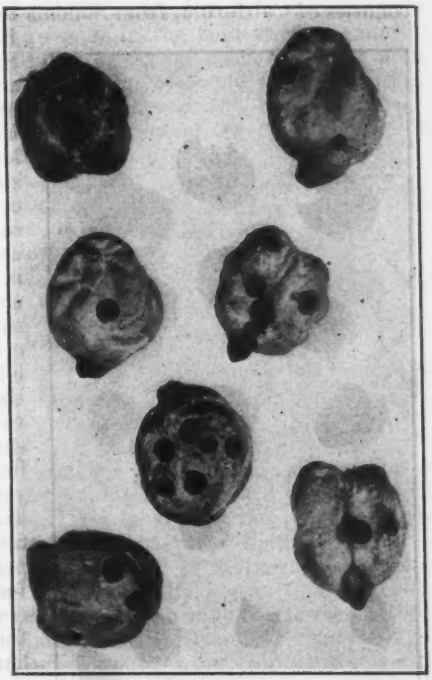

FIG. 16.—Chick-peas affected by the southern cowpea weevil. Compare these with the two-sectioned chick-peas at the bottom of Figure 22. Twice natural size

THE BROAD-BEAN WEEVIL [16]

The broad-bean weevil closely resembles the common pea weevil, being about the same size, one-fifth of an inch long, and of similar appearance. It can, however, be readily distinguished by its much narrower thorax and fainter markings, as a comparison of Figures 20 and 10 will show.

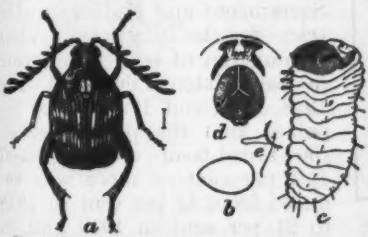

FIG. 17.—Cowpea weevil: *a*, Adult male; *b*, egg; *c*, postembryonic larva; *d*, front view of head of same; *e*, thoracic leg of same; *a*, six times natural size; *b–e*, more enlarged. (Chittenden)

The broad-bean weevil (fig. 20), sometimes called the European bean weevil, is common and destructive in Europe and North Africa. While it feeds upon various sorts of beans and peas, it appears to prefer the broad or Windsor beans. (Fig. 21.) Although it has been found from Canada to Texas in Windsor beans imported into various parts of this country, the first discovery of its definite establishment in the United States was made in 1909 at San Luis Obispo,

[16] *Bruchus rufimanus* Boheman.

Calif., where it was injuring the broad or Windsor bean (*Vicia faba*) grown for stock feed.

Since then, and up to 1920, it has spread to include the coastal counties of California, from Sonoma to San Luis Obispo, besides San Benito, Santa Clara, Alameda, San Joaquin, Sacramento, Yolo, and Napa. Practically every broad bean entering a New York warehouse is more or less damaged by this pest. A single grub in its development consumes approximately 3 per cent of the bean. Sometimes as many as six weevils develop in a single bean. Beside the actual amount of seed consumed, there must be considered the frass of the insect left behind in the seed, and this still further reduces the value of the crop. It has been stated that of the entire broad-bean crop of California for the years 1916, 1917, and 1918, 31.21, 18.01, and 43.08 per cent, respectively, were above the 15 per cent limit of weevil infestation allowed by the Federal pure food law, and therefore could not be shipped unless hand picked. In 1916 the average percentage of infestation for the entire 1916 crop in the Halfmoon and Gilroy regions was above the 15 per cent limit, while the same was true for the Sacramento and Halfmoon districts for the 1918 crop. After a campaign of seed fumigation in San Mateo County during 1918, 1919, and 1920 it was reported that the percentage of the broad-bean crop infested 15.1 per cent or more was reduced from 43 per cent in 1918 to 21 per cent in 1919 and to 17.8 in 1920. Since beans uninfested, or infested less than 15 per cent, were worth during these years from 5 to 6 cents per pound, and others only 2¼ to 3 cents, it is easy to appreciate the dollars and cents value of concerted action among growers in applying cheap, but effective, remedial measures.

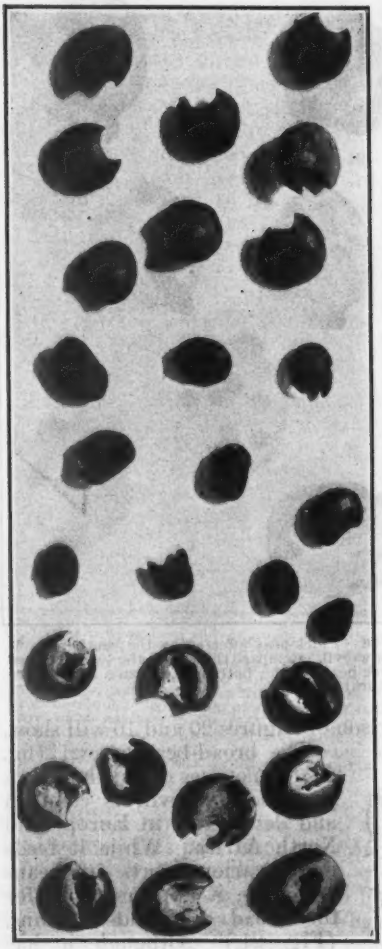

FIG. 18.—Lentils of two varieties showing injury by the lentil weevil. While only one lentil weevil matures in a single seed, it is capable of practically destroying that seed, as indicated by the sectioned seeds at the bottom of the illustration. Somewhat enlarged

The following biologic facts are taken from a report of experiments conducted at Alhambra, Calif.[17] The egg stage lasts from 9 to 18 days, the larva stage from 10 to 15 weeks, the pupa stage from 7 to 16 days, and the beetle lives from 1 to 8 months. The eggs are laid on the green bean pods in the field from the middle of March to the middle of May; the larvæ reach maturity from August to October, while the adults can be found from August to the following June. The broad-bean weevil has but one generation each year and can not start new generations in dried seed in storage. That is, such beetles as emerge from the seeds in storage have developed exclusively from eggs laid in the field upon the green pods and can do no further injury in warehouses.

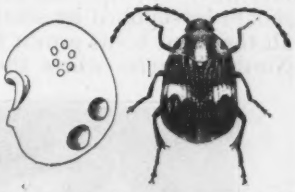

FIG. 19.—Mexican bean weevil: Adult weevil with line to left indicating actual length. Infested bean to left showing two emergence holes and six eggs. (Chihttenden)

WHY WEEVILS LIMIT ACREAGE PLANTED TO CERTAIN LEGUMINOUS FOOD CROPS

It has been pointed out already that infestation nearly always takes place in the field while the crop is maturing. With garden or Canada peas, lentils, and broad or Windsor beans infested with the pea weevil, the lentil weevil, and the broad-bean weevil, respectively, this is always the case, for these weevils never breed in dried seeds. Other species that breed in dried seeds, as well as in the field, may spread in storage to uninfested seeds and badly infest them. It is generally known that the colder the winters the shorter the growing season and the fewer the bean and pea weevils that survive the cold of winter and are ready to fly to the fields to start the infestation of the growing crop by laying eggs upon the pods. The farther south one goes the more mild the winters become, the longer the growing season, and the greater the number of weevils that can live through the winter.

FIG. 20.—Adult of the broad-bean weevil. Enlarged six times. (Chittenden)

As far south as the District of Columbia and the adjacent tidewater country of adjoining States, therefore, overwintering weevils attack the beans and peas in large numbers and succeed in years favorable for them in laying so many eggs upon the pods that each developing bean becomes affected and often may support as many as 20 to 28 weevil grubs. Because of the long, warm falls and the length of time the plants are allowed to remain in the field after the crop has ripened, either standing in the ground or pulled and stacked, these grubs are given every opportunity to develop into adults or at least to become very well grown in an unusually large number of cases, and therefore they cause greater damage than do weevils in bean fields farther north. Thus beans grown in latitudes south of New York City, except in higher altitudes, as in the

[17] CAMPBELL, R. E. THE BROAD-BEAN WEEVIL. U. S. Dept. Agr. Bul. 807. 22 pp., illus., 1920.

mountainous regions of the Alleghenies, become more infested than those grown north of that latitude. As weevils in beans are not killed so easily as are many other insects, and as their presence in numbers in beans is objectionable whether beans are grown for food or for planting, even when the grubs have been killed (fig. 22), the growing of beans on a commercial scale for dried seeds has largely been given up in our more southern latitudes. This explains the question often asked why beans and peas grown in portions of California, Michigan, New York, Washington, Oregon, or Idaho, or even in Canada, find their way into our southern markets, which one would expect should be supplied by southern-grown beans and peas. Practically all the dried beans grown for seed and for food are grown in these Northern States where the bean weevils are not able, because of

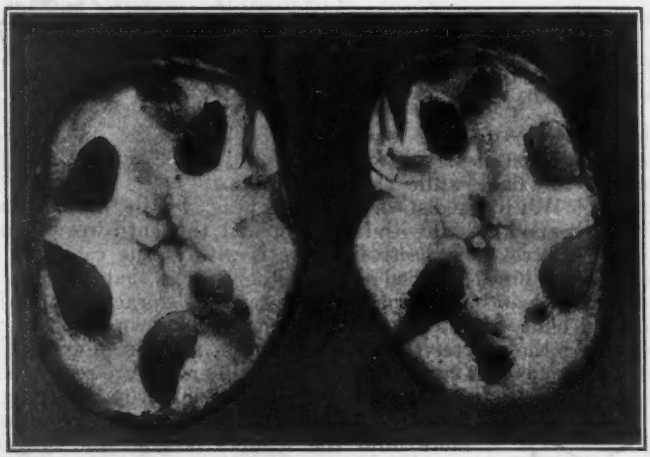

FIG. 21.—A broad, horse, or Windsor bean, cut open to show the damage caused by grubs of the broad-bean weevil. Only one generation of this weevil occurs each year. As each cavity represents the feeding of one grub, this bean is badly affected. Considerably enlarged

climatic checks, to cause so much damage. Of course weevils do not affect the growing beans to be eaten green, as string beans or green shelled beans, for such beans are not, at the time of gathering, infested; or if infested, the grubs are too small to interfere with their value as food.

GERMINATION AFFECTED BY WEEVIL ATTACK

The germination of beans, peas, and cowpeas is likely to be seriously affected by the development of weevil larvæ. If the embryo is destroyed by the larva, or if too much of the bean substance is eaten, the seeds can not grow.

Beans as badly infested as those shown in Figures 1, 7, and 23 are worthless for planting. As the young bean or pea plant depends upon the food stored in the seed to give it its first start, the destruc-

tion of any portion of the seed by weevils lessens by so much the vigor of the plant. In one experiment on record, only 50 per cent of infested beans germinated, and of these 30 per cent were so badly injured that they could not develop into normal plants. The smaller the seed, the greater proportional damage a single weevil grub can cause. One grub ruins a small cowpea seed (fig. 14) or a lentil (fig. 18), whereas it would not so seriously affect a large seed like the Lima bean. The germination of broad beans infested with 1, 2, 3, and 4 or 5 broad-bean weevils was found to be reduced from a normal of 95.7 to 82.7, 72.7, 71.1, and 69.6, respectively. In examining 50 garden peas infested by the pea weevil, 33 were found with the embryo wholly or partially destroyed, and in another case only 69 out of 275 infested peas had undamaged embryos or germs.

FIG. 22.—Beans (six upper seeds) and chick-peas (two lower seeds). The skin of the beans has been removed to reveal the cavities eaten out by the common bean weevil grubs. The grubs have been killed by fumigation and have turned black. Note the white paperlike cell or cocoon about each of the grubs. The chick-peas have been cut open to show how the larvae of the southern cowpea weevil can burrow to the very center of the seed. Slightly enlarged

HEATING DUE TO INFESTATION

It is a well-known fact that beans and peas, as well as grains, will heat if insects become sufficiently abundant in them. In bean warehouses where the seeds are stacked, as shown in Figures 26 and 27, centers of weevil infestation can be detected by walking past the tiers of sacks and allowing the hand to pass over the sacks. Experience soon makes it easy to detect heating sacks. Heating seeds also produce an odor quickly detected by experienced persons when they enter a warehouse after it has been closed for a few hours.

The ability of bean and pea weevils to produce heating of the seeds is of great importance. Were it not for this ability, owners could rest assured that if warehouses were open to outdoor temperatures below 50° F. no injury from weevils would take place. Certain weevils develop most quickly when the temperature ranges between 75° and 95°, and egg laying is greatly stimulated by these higher temperatures. At temperatures ranging from 75° to 95° development of the southern cowpea weevil has been known to be completed in as few days as 18; hence heating caused by weevil infestation, with the accompanying increase in moisture content of the seeds, may

result in an outbreak of weevils at a season of the year when least expected. The temperature of a 240-pound sack of chick-peas infested by the southern cowpea weevil may be raised by infestation to at least 103°. It is not uncommon in some warehouses to find a considerable number of sacks the temperature of which has been raised to over 80° or 90°. In one instance, when the daily maximum temperatures ranged between 50° and 58°, sacks within 2 feet of an open window registered 102°. The temperature in the spaces between heating sacks was raised in this warehouse from 58° to a minimum of 70° and a maximum of 78°. At 58° adult weevils were too cold to migrate, but at 70° to 78° they were very active and were spreading from heating sacks to surrounding sacks and laying eggs upon previously uninfested seeds.

This effect of heating, due to infestation, upon spread of injury from sack to sack, to say nothing of increase in infestation within the individual sacks during cold weather, should be understood by those holding beans and peas, else a genuine loss will come upon them

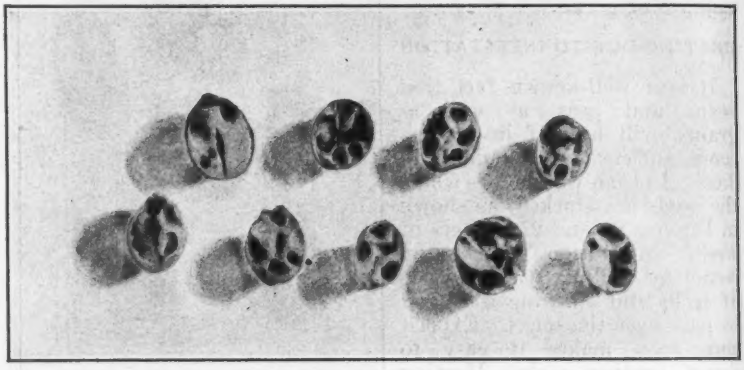

FIG. 23.—Navy beans cut crosswise to prove how the common bean weevil can ruin seeds for eating or planting. About natural size

unawares. Fumigation with hydrocyanic-acid gas (p. 25) kills the insects, reduces the temperature to normal, and stops spread. Fumigation with any efficient fumigant will doubtless do the same.

REMEDIES

No group of seed pests can be more easily controlled in storage than pea and bean weevils. Once seeds are dried and housed they can be protected from destruction. Owners should watch their crop and apply treatment at the first sign of infestation. Any remedy that lessens the number of weevils present in the field has a direct effect upon the number of weevils to be fought in storage, and vice versa.

PLANTING OF INFESTED SEEDS WILL NOT CAUSE AN INFESTED CROP

Although it is better not to plant infested beans or peas because the weevils have injured the food content of the seed upon which the

seedling plant depends for its first rapid growth, the planting of seeds containing live weevils will not cause the following ripening crop to become infested. The old belief that weevils emerging from weevily seeds that have been planted can live long periods in the bean field or garden and be ready to infest the ripening crop has been proved false. Experiments have also proved that the scattered beans left exposed on the ground at harvest time are not a source of infestation from the standpoint of the next year's crop.

REMOVAL OF BREEDING PLACES IMPORTANT

The removal of dried beans and peas and their straw or vines is very important. Thus in bean-growing regions of California it has been proved that bean weevils will multiply for several years in piles of bean straw on bean plantations and that from such piles weevils fly to the ripening beans and cowpeas and infest the new crop. Small quantities or beans in warehouses, barns, attics, or any other storage place may be the source of thousands of weevils which fly to the fields and gardens to infest the new crop. In fact, it is now believed that this source of infestation is the only one, and that if bean growers will cooperate intelligently and thoroughly in the destruction of insects in their storage places, no infestation of the crop will occur. Many farmers and gardeners along the Atlantic seaboard have weevily beans in their storerooms which breed weevils throughout the summer following the fall when the seeds were harvested, and from these seeds enough weevils fly to the near-by gardens and fields to cause the new crop of beans to become weevily.

HARVEST, THRESH OR SHELL, AND SACK AS SOON AS POSSIBLE

Because some adult weevils emerge in the late summer and fall, according to the latitude, leguminous crops subject to weevil attack should be harvested as soon as possible after reaching maturity. The seed should be threshed or shelled at the earliest possible moment in order that the seeds may be more easily and cheaply treated to keep the weevil grubs from feeding and maturing. Storing in the pod does not confine the weevils. The grubs continue their development and transform to the adult in the unshelled as well as in the shelled seeds. Adult weevils can gnaw their way out of dried pods, as shown by the exit holes in the pods of Figures 24 and 25. The weevils in large bulks of unthreshed or unshelled beans or peas can not be satisfactorily treated. There is only one answer to the often-asked question, "Is it better to store beans or peas in the pod or shelled?" Shell the seeds and treat them if you suspect weevil injury.

FUMIGATION

Weevils may be killed in storage by fumigation with carbon disulphide, carbon tetrachloride, or hydrocyanic-acid gas.

CARBON DISULPHIDE

Fumigation with carbon disulphide (CS_2) is one of the simplest remedies for weevils. The nature and use of this fumigant is dis-

cussed in Farmers Bulletin 799, which can be had upon request from the United States Department of Agriculture. Carbon disulphide is purchased as a liquid in iron drums or tin cans and weighs about 10½ pounds per gallon at ordinary temperatures. Upon exposure

FIG. 24.—Storing beans, peas, or cowpeas in the pod will not prevent the weevils from ruining the beans if they are already in the seeds. Neither will it prevent them from emerging, as indicated by the holes they have made in the pods shown above in making their escape from the seeds. One pod has been cut to expose the infested beans within. Work of the common bean weevil. One and one-fourth times natural size

to air the liquid evaporates or volatilizes, forming a foul-smelling gas that is about twice as heavy as air. Because the gas is heavier than air and evaporates more quickly if a larger surface of the liquid is exposed to the air, the liquid should be poured out into shallow

pie tins or similar shallow dishes and placed upon the top of the seeds to be fumigated. Seeds will not be injured or poisoned if the liquid is sprinkled or poured directly upon them. In estimating the quantity of carbon disulphide needed, the volume of cubic space in the container in which the fumigation is done should always be considered—not the amount of space occupied by the seeds.

If used according to directions, carbon disulphide will not injure the germination of thoroughly dry seeds or affect their value for food. The disagreeable odor passes away after seeds fumigated have been aired. While carbon disulphide has become a standard fumigant and has been used for years without trouble by many individuals and firms, it is always timely to call attention to the fact that the gas is explosive and inflammable if fire is brought close to it during fumigation. Fire, as used here, includes even a lighted cigar, lighted lantern, or the spark from an electric fixture.

Seeds to be fumigated should be placed in an air-tight container. This may be a tin pail, wash boiler, barrel lined with heavy paper, galvanized-iron garbage can, or other receptacle, or a specially constructed fumigation box or room, according to the quantity of seed to be fumigated. One of the simplest satisfactory containers for fumigation on a small scale is a water-tight barrel. The tighter the receptacle the better the results. Satisfactory results can not be secured if fumigation is attempted in a room full of cracks.

Carbon disulphide should be used at the rate of from 4 to 20 pounds to each 1,000 cubic feet of space to be fumigated, the quantity to be used varying with the tightness of the container and the temperature. The liquid should be poured over the top of the seeds to be fumigated or poured into shallow dishes set on top of the seeds. It quickly vaporizes, and as the gas is heavier than air, it sinks to the bottom of the container, filling all the air spaces. Fumigation should continue from 24 to 48 hours, although most of the actual killing is done during the first 6 to 8 hours of exposure. It is always better to use too much rather than too little carbon disulphide.

FIG. 25.—Pod of field pea showing exit hole of cowpea weevil. This pod was taken from a bale of field-pea hay grown in Florida and indicates that even field-pea hay grown only for cattle feed may be instrumental in offsetting community cooperation to lessen weevil injury. One and one-fourth times natural size

Beans, cowpeas, and peas can be stored and fumigated conveniently in water-tight barrels. These should be filled to within a few inches of the top with seeds. In fumigating, pour one-half cup or more of carbon disulphide on the seeds and then cover the top of the barrel with a double thickness of heavy wrapping paper tied tight around the top, or several sacks weighted down with boards. A wooden cover is also useful in keeping in the fumes.

Fumigation with carbon disulphide to give the best results should be carried on at or above a temperature of 75° F. It is not effective at temperatures below 60°. After fumigation the seeds should be examined occasionally and given a second or third fumigation in case living weevils are found.

Carbon disulphide costs from 6 to 25 cents a pound. It is cheapest when purchased in 55-gallon drums (550 pounds.) The cost is greatest when the liquid is bought in 1-pound cans and then may range from 25 to 40 cents per pound.

To these prices must be added transportation costs. Farmers throughout the country can purchase carbon disulphide of local drug stores, but prices under such conditions often are exorbitant. County agents, boards of trade, or other public-spirited local organizations can purchase carbon disulphide and furnish it at cost to farmers in the vicinity. This has been done in certain southern towns with the result that farmers have secured carbon disulphide of excellent quality [18] at lowest price. If local firms can not supply carbon disulphide, the names of firms in a position to fill orders may be obtained upon application to the Bureau of Entomology, United States Department of Agriculture.

Remember, if you do not get results with carbon disulphide the trouble is (1) with the way you apply it; (2) your container is not tight; (3) your dealer has sold you poor liquid; or (4) you have fumigated when it is so cold that no one can get good results.

Remember that large business firms and many farmers use carbon disulphide successfully and that its use on farms is on the steady increase. Nothing speaks better for any control measure than its steady use by successful business men, no matter whether they are farmers or seed brokers.

CARBON TETRACHLORIDE

Carbon tetrachloride (CCl_4) is a fumigant that has been used as a substitute for carbon disulphide in fumigation work, since it has the advantage over carbon disulphide of being noninflammable. When pure, carbon tetrachloride is a thin, transparent, colorless liquid, with a pungent, aromatic odor. Except for being noninflammable, it is similar to carbon disulphide in all essential features, from the standpoint of application. It costs from 11 to 60 cents a pound and is not more than one-half as effective as carbon disulphide. It is not likely to take the place of carbon disulphide because of its inferior killing qualities and its somewhat great cost per pound. Its great advantage is its noninflammability.

If carbon tetrachloride can not be had from local firms the names of firms supplying this chemical may be obtained upon application

[18] Unscrupulous dealers sometimes sell inferior lots of carbon disulphide. Dealers selling liquid containing less than 98 to 99 per cent actual CS_2 violate the Federal insecticide act and are liable to prosecution in Federal courts.

to the Bureau of Entomology, United States Department of Agriculture.

HYDROCYANIC-ACID GAS

Fumigation with hydrocyanic-acid gas is recommended when large quantities of beans, peas, cowpeas, or chick-peas are found infested with weevils. The seeds must be in sacks and so stacked that the gas can reach several sides or portions of the sacks. Chick-peas stored in 240-pound sacks, and stacked as shown in Figures 26 and 27, were almost perfectly protected by fumigation. It has been found in the fumigation of warehouses, sometimes as large as 150 by 150 by 20 feet, and containing as many as thirty thousand 240-pound sacks of chick-peas, that hydrocyanic-acid gas can be depended upon to eliminate infestations almost completely. Fumigation with this gas for the

FIG. 26.—Carload lots of 240-pound sacks of chick-peas as stacked in badly infested warehouse. Samples taken throughout length of sack proved that hydrocyanic-acid gas penetrated to the very center and that infestations were killed

control of bean and pea weevils has proved so satisfactory that its use is now an established practice with certain firms. For seed so stored the dosage should be increased from the normal dosage of 1 pound of sodium cyanide for each 1,000 cubic feet of space to be fumigated to 2½ pounds per 1,000 cubic feet. Since it is extremely poisonous, hydrocyanic-acid gas should be used only by responsible persons who are thoroughly informed on the subject of fumigation. As the gas is lighter than air and readily escapes, does not injure the seeds for planting or for food, injures no warehouse equipment, and is non-inflammable when mixed with air in the proportions used in fumigation, it lends itself for use in almost any warehouse section if the fumigation is properly timed and supervised. Full details for fumigation with hydrocyanic-acid gas may be obtained from this department.

HEAT

Heat as a means of killing weevils in legumes is growing in favor. Small quantities of seed grown on the farm or in the town garden

can be treated by placing them in an oven after they have been spread rather thinly in shallow pans and heating them to from 120° to 145° F. for several hours. An old remedy is to dip seeds into boiling water for one minute. Holding seeds in boiling water for more than one minute will injure their value for planting purposes and immersion for even one minute has been known to affect germination. On removal they should be spread out immediately and dried rapidly.

Weevil development in large quantities of beans, peas, and cowpeas can be stopped by a process known as kiln-drying. This process consists in heating the seeds to a temperature of 120° to 145° F., or higher, while they are being passed through a machine called a drier. This treatment not only removes a portion of the moisture in the seeds but also kills all insects in them. The loss of moisture may be an item of importance if sales are made by the pound, yet investi-

FIG. 27.—Interior view of warehouse containing thirty thousand 240-pound sacks of chick-peas with a retail value of $864,000 at time of treatment. Infestations breaking out under such abnormal storage conditions were controlled by fumigation with hydrocyanic-acid gas

gators claim that seeds containing 20 per cent of moisture or less are not easily infested by weevils, hence excessive drying with the heat not only kills the weevils but renders seeds less susceptible to reinfestation.

The embryos of the common bean weevil are killed when exposed to 125.6° F. for 10 minutes; the newly hatched larvæ die in 7 minutes at 131°; full-grown larvæ in beans die in 20 minutes at 131°; and pupæ die in beans when exposed for 25 minutes at 131°. Adults are killed by a 4-minute exposure at 131°. These data can not be relied upon when large masses of seed are to be treated. The investigator who obtained them found that 9 hours were required for the center of 2 quarts of beans inclosed in a tight paper bag to reach the surrounding temperature of 131°. Cowpeas infested with the southern

cowpea weevil were not absolutely sterilized from an insect standpoint when exposed to 140° for 5 minutes, though all the weevils were killed when the seeds were exposed to this temperature for 10 minutes in an oven. These results in killing the southern cowpea weevil were secured under conditions more favorable than those likely to occur in commercial bean establishments, hence it was recommended that seeds be exposed in commercial treatment to 146° for 20 to 30 minutes. Temperatures above 150° seemed to weaken the resulting plants, but germination took place even after the seeds had been subjected to 190° for 10 minutes. Commercial coffee roasters are used by certain bean brokers for the destruction of weevils by heat. Seeds have been treated by the carload in such roasters and guaranteed to remain free from injury by bean weevils at least during transit in carload lots. A list of firms that manufacture apparatus for heating seeds will be furnished upon application. As is done in kiln-drying, the seeds should be spread out in order that all may be affected quickly and uniformly by the heat. When thus spread out an exposure to 131° for 1 hour should be sufficient.

Heat is not recommended for the control of the broad-bean weevil in broad or Windsor beans. Exposure to temperatures ranging from 120° to 140° for 5 to 40 minutes did not kill this apparently more hardy insect and the higher temperatures had an injurious effect upon germination.

COLD AND COLD STORAGE

Weevils will not feed and cause damage at low temperatures. It is not known at what temperature development ceases, but no development takes place at or below 50° F. Cowpeas can be kept free from weevils if held in storage at a temperature of 32° to 34°. It is claimed that exposure for a season at this temperature does not affect the germinating power of the seed. Investigations conducted in this bureau indicate that no stage of the common bean weevil can withstand 56 days of cold storage at 31° to 32°, although they may survive more than 66 days at 36°. The larvæ, it appears, succumb to cold-storage temperatures more readily than do pupæ or adults. The storage room should be kept as dry as possible and the seeds should be handled in sacks as in warehouses. Cowpeas held for a season at 32° to 34° were found to lose their germinating power no sooner on removal to normal temperatures than cowpeas not thus exposed to cold. Seeds removed from cold storage to warm temperatures are likely to sweat, and if care is not taken to eliminate this surface moisture by drying or proper ventilation, moldiness may result. There is some doubt as to the real need of incurring the expense of cold storage, as seeds can be protected more cheaply by fumigation under storage conditions thought by the majority of seed owners to be better for the seeds.

LIME OR DUST AS PROTECTION TO SEED

In the Southern States, where weevils cause such great injury to stored seeds, certain farmers have resorted to mixing their seed cowpeas with dry road dust or air-slaked lime. Tests prove that the storage of cowpeas with air-slaked lime at the rate of 1 part by

weight of lime to 6 to 8 parts of peas is a great help in protecting seeds. The dust or lime does not necessarily kill the weevil grubs developing in the seeds if these are already in the seeds at harvest time, but it prevents adult weevils either from emerging, or, if they succeed in emerging, from laying their eggs on the seeds for successive generations. The dust or lime, in other words, prevents continued breeding in storage. Either substance would probably be a nuisance if mixed with cowpeas intended for food if the seeds contained many emergence holes, as the lime or dust would work into these holes and be difficult to remove. If seeds are known to be free from weevils and are stored in tight barrels, bins, or other similar containers, a top layer of air-slaked lime about one-half to 1 inch thick, if maintained, will prevent weevils from gaining access from without and starting an infestation.

COMMUNITY EFFORT TOWARD CONTROL

Anyone can protect beans and peas from further weevil injury after they are once dried and in storage. If loss occurs in storage, owners have only themselves to blame, for weevils can be effectively controlled at a cost very slight as compared with the value of the seeds protected and the increased value of the seeds after thorough treatment.

But no one person can prevent his beans and peas from becoming infested while they are developing in the garden or field unless he and his neighbors are willing to get together and pledge to treat their seeds in storage and to destroy other breeding places, such as bean-straw piles. Many adult weevils fly to fields from storage bins about the time the seeds are beginning to mature. A negligent neighbor may be the cause of much neighborhood infestation by the flying of his weevils to developing crops or into warehouses.

Community effort to reduce weevil losses can be made effective in localities where beans and peas are grown on a commercial scale. It is doubtful if concerted action can be secured in towns or cities where there are many small gardens yielding but a few seeds, for these small quantities of seed are of too little value to move their owners to action. The University of California during 1918–1920 conducted a campaign of community effort, in San Mateo County, Calif., directed against the broad-bean weevil (p. 15) and found that by working through the county agent and fumigating the crops after they were placed in storage the infestation in the field was reduced from 43 per cent in 1918 to 21 per cent in 1919 and to 17.8 per cent in 1920.

Similar community campaigns are being conducted in other regions for the control of the common bean weevil and the southern cowpea weevil. The county agricultural agent has here a worth-while field for action along with his many others. To succeed, all farmers in a district should treat their seeds and dispose of all refuse and bean straw before the next bean crop approaches maturity.

TREATMENT DOES NOT PREVENT REINFESTATION

Treatment of legumes subject to infestation by weevils that can breed generation after generation in storage will not keep them free from weevils if they are stored so that adult weevils can get to them

and lay eggs on them. The application of remedial measures may kill all weevils in the seed at the time of treatment, but it should be remembered that no treatment has a lasting effect in preventing reinfestation from outside sources. Seeds once treated should be stored in rooms free from adult weevils, or placed in tight barrels or sacks made of closely woven material, and should be examined occasionally as a guard against subsequent infestation.

When large quantities of seeds are brought together under one roof, they usually represent the crops of many farmers whose local conditions may have varied to such an extent that one carload lot of seed may be free of infestation while the next may be slightly or heavily infested. Experimental work has proved that sacking seeds in one thickness of lightweight close-weave muslin will prevent un-

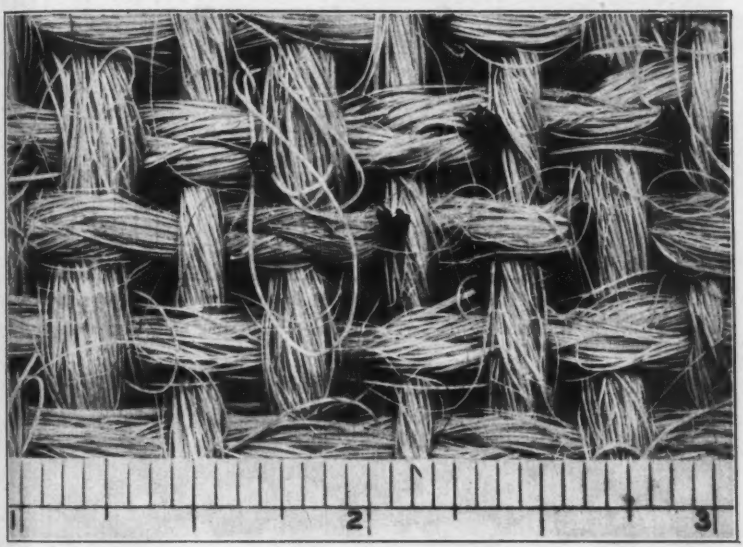

FIG. 28.—Section of jute sack having four strands to the inch. Such sacks are of no value in preventing spread of infestations from sack to sack in warehouses. The adult weevils can leave or enter such sacks at will

infested seed from becoming infested even though there are many weevils and weevilly seeds close by. It is not practical in large seed warehouses to use sacks of lightweight muslin, yet a study in 1917–18 of conditions in large warehouses containing many carload lots of seed indicates the value of closely woven sacks. Jute sacks with but four strands to the inch (such as shown in fig. 28) are no protection to the seeds within the sack and do not prevent weevils developing in the sacks from crawling out and migrating to and laying their eggs upon seeds in other sacks of similar weave. But seeds sacked in heavy cotton sacks of close weave with 24 strands to the inch are apparently perfectly protected from infestation from without. (Fig. 29.) Some such sacks contained badly damaged and heating seed but the infestation was held within them and prevented

from spreading to adjoining sacks by the tightness of the sacks. The common bean weevil and the southern cowpea weevil can eat holes in paper sacks and escape, but do not eat through cloth. There is

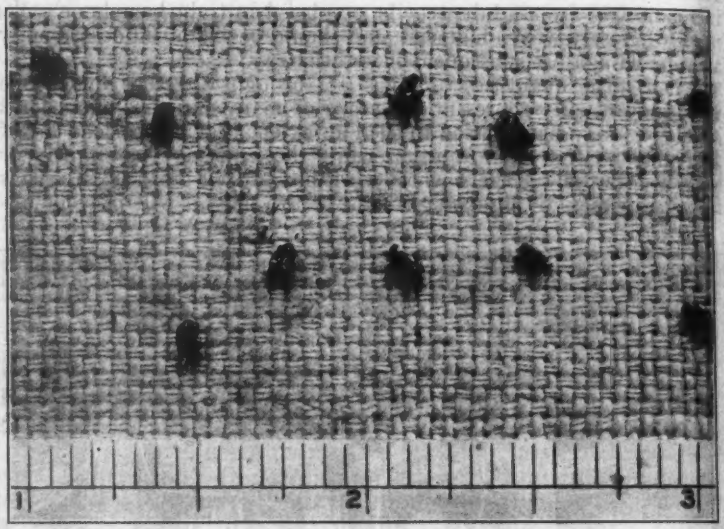

FIG. 29.—A heavy cotton close-woven sack with 24 strands to the inch. Sacks made of this material are on the market and have proved their effectiveness not only in preventing weevils from leaving the sacks but also in protecting uninfested seeds from infestation from without

a great deal in favor of a tight cloth sack, not only for protecting uninfested seeds from infestation from outside sources but also in preventing infestations from spreading.

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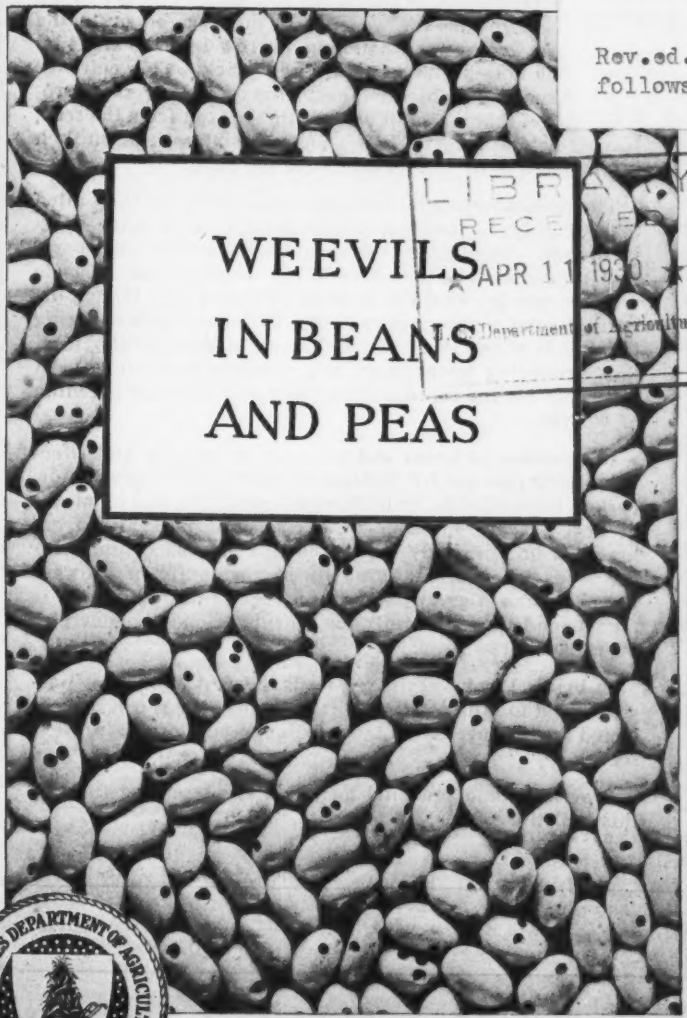

WEEVILS IN BEANS AND PEAS

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BEANS, peas, and cowpeas are often damaged seriously in storage and in the field by weevils. Velvet beans, soy beans, and vetches are rarely infested in this country. Bean, pea, and cowpea weevils not only destroy much of the Nation's food in the form of leguminous crops but are responsible for a curtailment in the acreage planted to these crops. They never attack corn and wheat.

A large percentage of the initial infestations occurs in the field, where the parent weevil lays her eggs on or in the pods. The grubs, upon hatching, burrow into the seeds by gnawing a hole no larger than a pin prick. This entrance hole is usually not observed, hence the often expressed erroneous belief that the adult weevils that eat out from the seed, leaving behind a round hole about one-sixteenth of an inch in diameter, have " developed from the germ."

The most injurious bean and cowpea weevils in the United States can breed generation after generation in dried seeds in storage. During the hottest summer weather one generation requires about one month for development. Female weevils may lay as many as 50 to 58 eggs a day, though the average total number of eggs laid by an individual during her life is about 100. Infested seeds in bulk usually heat, thus producing temperature and moisture conditions most favorable for the rapid development and vigorous breeding of weevils.

Infestations in beans and peas can be quickly and effectively stamped out by fumigation with carbon disulphide, carbon tetrachloride, or hydrocyanic-acid gas, and by means of heat or cold storage. Weevils can be prevented from breeding in storage by mixing dust or air-slaked lime with the seeds. Concerted action by a community of growers has been known greatly to reduce weevil infestations and is recommended unreservedly for consideration in commercial bean-growing areas.

In brief: Plant weevil-free seeds, harvest as soon as possible, treat to kill weevils, and store where seeds can be protected from reinfestation by weevils spreading from infested seeds.

Preventive and remedial measures are described fully in this bulletin.

Washington, D. C.

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WEEVILS IN BEANS AND PEAS

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SERIOUS LOSSES CAUSED BY BEAN AND PEA WEEVILS

BEAN AND PEA WEEVILS are by no means new pests. They belong to a class of insects that cause farmers and merchants an annual loss of many millions of dollars. One Province of Canada alone suffered from the ravages of the pea weevil to the extent of over $1,000,000 in a single year. It was estimated in 1902 that the acreage in field peas in Ontario would have been 1,000,000 instead of the actual 532,639 planted had it not been for fear of the pea weevil. Since the introduction from Europe of the broad-bean weevil into California about 1909, the pest is estimated to have reduced the acreage planted to Windsor beans 25 to 75 per cent, and in Alameda County, formerly a large producer, there is now practically no commercial acreage of these beans. The common bean weevil has been one of the chief factors in discouraging the production of field beans south of the latitude of New York, except in the higher altitudes, and is to-day one of the worst enemies of garden beans of all varieties grown in the East. Few realize that the ravages of this weevil have forced farmers of many sections—as in the coastal regions of the Middle Atlantic States—to discontinue the production on a commercial scale of this valuable food crop and to turn their attention to other crops. The cowpea is now recognized as one of the most valuable cover crops for enriching the soil of the Southern States, and agriculturists claim that one of the drawbacks to its more gen-

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eral use for this purpose and for fodder is the susceptibility of cowpea seed to weevil attack. The cowpea weevils are the worst pests of cowpea seed. They are a big factor in maintaining, in years of normal production, the high cost of seed, and in the consequent curtailment of the use of this plant as a soil builder. These weevils, also, because of the rapidity with which they destroy cowpeas grown for human consumption, have caused seedsmen and merchants to view with suspicion cowpeas grown in certain sections of the South, and this attitude has had a depressing effect upon the production of cowpeas for food. Yet the South is a veritable Eldorado for the production of leguminous crops for food once weevils are controlled. It is evident, therefore, that bean and pea weevils should be charged not only with the damage they cause leguminous foods actually produced, but also with the indirect losses to the country due to the reduction in the areas planted to beans, peas, and cowpeas.

FIG. 1.—Navy beans showing the emergence holes of weevils. Each of these holes is made by a weevil as it matures in the seed and leaves by cutting out a piece of the skin. All except the five small beans at the bottom have been injured by the common bean weevil. The five small beans were grown in Central America, and are infested by the Mexican bean weevil. About natural size

LOSSES OFTEN DISCOVERED TOO LATE

Injury to edible legumes usually is observed first after the crop has been in storage for several months. Many believe that once the crop has been harvested it needs no further attention. Seeds put away at time of harvest are sometimes not examined again until the following planting season, when they are found "buggy" or "weevily" and badly damaged. The town or city gardener has proudly put away for winter consumption beans grown during the previous summer, only to find them worthless as food and full of holes and honeycombed by grubs when later he opens the jar or sack in which they have been stored. Wonder is often expressed that seeds apparently sound when put away for the winter, and

kept always well covered, should be found later injured by weevils. Because small round holes (see title-page and fig. 1) and weevils appear later in seeds seemingly perfect when harvested, a belief is current among many that bean and pea weevils develop spontaneously from the germ of the seed. That there is no foundation for such a belief is shown by the facts following.

HOW BEANS AND PEAS BECOME INFESTED

Bean and pea weevils, like many other insect pests, pass through several marked changes in form and habits before reaching maturity. The story of development is shown in Figure 3. The weevil that is seen crawling about among the seeds is the parent insect. Many of these fly from the storage room or house to the fields where beans

FIG. 2.—Field peas in bloom. Adult pea weevils begin laying their eggs on the young pods in the field. It should be remembered that the bean and pea weevils begin their attack on the seed while the crop is developing in the field. Photo by Vinal

and peas (fig. 2) are growing. As the bean and pea pods develop, the mother weevil lays whitish eggs, either on the outside or within the pods. These eggs are so small that they are often not noticed, for they appear as mere white specks upon the pods. From these eggs there hatch white grubs that burrow their way through the pod into the soft developing beans or peas. Because these grubs are so very tiny, the holes through which they enter the seeds are too small to be seen unless one searches for them with a microscope. Usually beans become infested first when they are nearly or quite full grown. As seeds expand and harden in the final ripening process the holes in the skin through which the grubs entered become less and less easy to find. The wound in the skin either becomes entirely healed over or remains similar in appearance to a small pin prick.

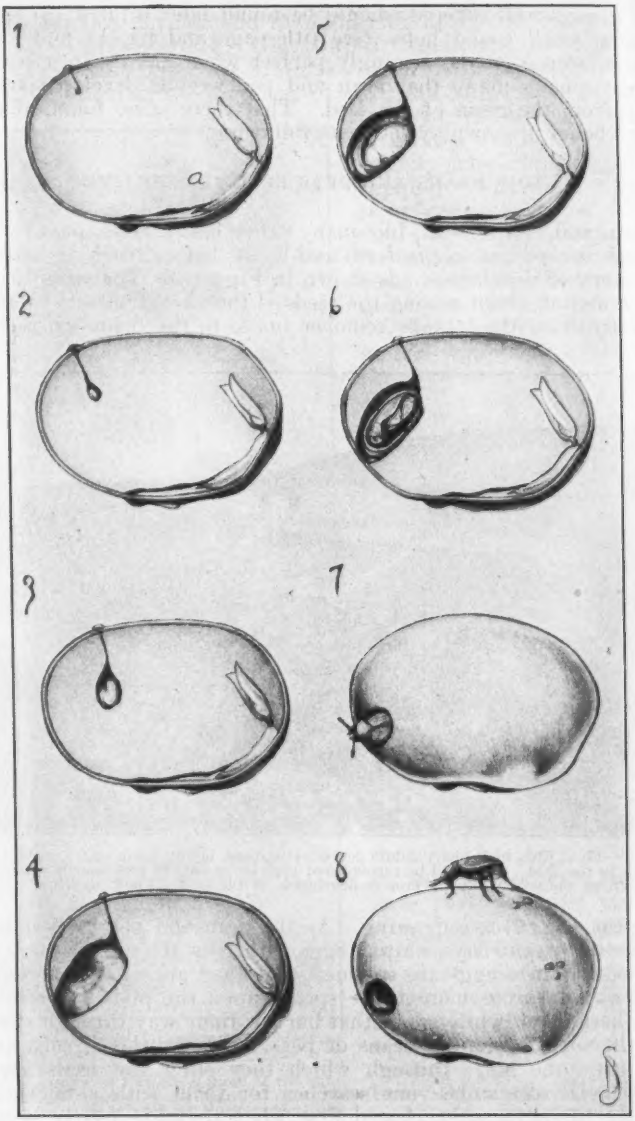

FIG. 3.—Life cycle of a cowpea weevil: 1, Cross section of seed showing embryo or germ at *a*, and on upper left side an eggshell and the small burrow made by the newly hatched grub from the underside of egg into the seed; 2, 3, and 4, larva or grub in different periods of growth, the larva of 4 being full grown; 5, pupa or resting stage, which is intermediate between the larva and the adult; 6, side view of beetle within the pupal cocoon and ready to gnaw the round hole in the seed coat so it can crawl out of the seed; 7, beetle has eaten a circular hole in the seed coat and is crawling out (note that this emergence hole is some way from the point of entry); 8, female beetle laying eggs upon the seed

Since beans and peas mature much faster than the weevil grubs within them, it happens that the weevil grubs are comparatively small or little developed, in many instances, when the crop is harvested (fig. 4) and placed in storage. Thus many seeds that appear outwardly in excellent condition in reality have weevil grubs hidden away in their interior, as shown in Figure 3.

WHERE WEEVILS IN STORAGE COME FROM

At harvest time grubs developing from eggs laid on or in the pods in the field may have devoured very little of the seed contents, but if the seeds are stored in a warm place, or in a climate where the weather is sufficiently warm, they continue to feed and become well grown. When well grown they have eaten out of the seed contents a cavity somewhat larger than themselves and extending outward to, but not puncturing, the skin of the bean. (Fig. 5.) The grub then

FIG. 4.—Wagon loads of field peas brought to mill to be threshed. Remember that the pea weevil, the broad-bean weevil, and the lentil weevil are the only weevils mentioned in this bulletin that can not breed in dried seeds in storage. For this reason any infestation by these weevils occurs only in the field while the crop is maturing; hence the weevil grubs are in the seeds at the time they are harvested, shelled, or threshed, and any treatment at that time, if done thoroughly, will prevent the development of holes in seeds resulting from the emergence of adult weevils

changes or transforms into the pupa (fig. 10, *c;* fig. 12, *c*) and later into the adult. This adult has a pair of sharp jaws which it uses like a pair of scissors to cut out a circular flap (fig. 6) in the bean skin, thus making the small round hole which is, to most gardeners, the first evidence that insects are in their beans. Through these openings the adults crawl out and by their presence in sealed jars and other containers cause much concern.

DESTRUCTION CONTINUES IN STORAGE

With the exception of the pea weevil that attacks the different varieties of peas, the broad or Windsor bean weevil, and the lentil weevil, the weevils attacking beans and cowpeas continue to produce

generation after generation in dried seeds in storage. (Fig. 7.) The pea and the broad-bean weevils will die in storage and can not reproduce unless they can find growing plants in which to lay eggs. But the ordinary bean and cowpea weevils lay eggs for successive generations as readily upon dried seeds in storage as upon the growing plants in the field. As each generation of weevils reduces the value of seeds for planting and for food, steps should be taken to kill, at harvest time, such grubs as may be in the seeds and thus prevent further losses. If this is not done the seeds become honeycombed by the feeding of generations of grubs and may be reduced to a powder. (Fig. 8.) Because bean and cowpea weevils can breed in dried seeds it is important not to store uninfested seeds near seeds that are infested, for the weevils spread rapidly and will soon infest the newer seeds.

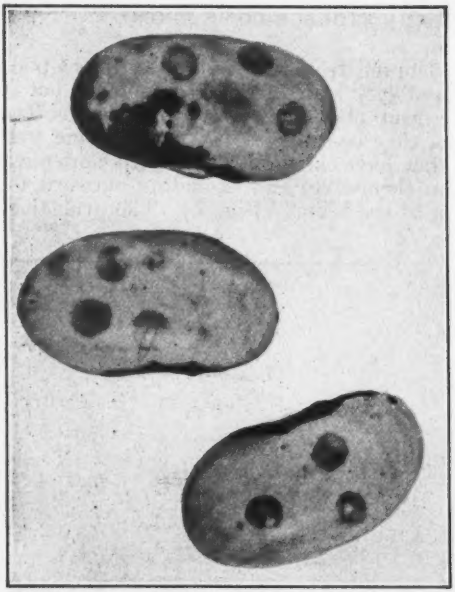

FIG. 5.—Beans in which the common bean-weevil grubs have become full grown and have eaten out from the interior of the bean to, but not puncturing, the skin. As they transform to adult, each insect darkens and this dark color shows through the thin skin and makes the dark, sometimes bluish, translucent spots in beans. Such spots indicate that seeds are infested. It should be remembered that while the grubs are still growing they are white, and seeds do not indicate their presence by any such dark spots as shown above. Three times natural size

THERE ARE DIFFERENT KINDS OF WEEVILS

Injury to leguminous crops is caused by more than one insect. Those considered in this bulletin are the pea weevil,[1] the common bean weevil,[2] the southern cowpea weevil,[3] the cowpea weevil,[4] the broad-bean weevil,[5] the lentil weevil,[6] and the Mexican bean weevil.[7] These are all found in supplies of beans, peas, cowpeas, or lentils in this country. Other bruchid weevils are sometimes found in imported seeds, but will not be discussed here.

GENERAL DESCRIPTIVE FACTS

The bean and pea weevils of the United States are all very small. None of them is longer than one-eighth to one-fifth of an inch. They are dull-colored with markings of white or black. For the

[1] *Bruchus pisorum* Linnaeus.
[2] *B. obtectus* Say.
[3] *B. quadrimaculatus* Fabricius.
[4] *B. chinensis* Linnaeus.
[5] *B. rufimanus* Boheman.
[6] *B. lentis* Boheman.
[7] *Spermophagus pectoralis* Say.

general shape, size, and arrangement of these markings, see Figures 10, 12, 13, 17, 19, and 20. Their eggs are from one-fiftieth to one-twenty-fifth of an inch long, white or whitish, and appear as specks (figs. 14 and 15) when laid on beans and cowpeas in storage.

The larvæ, or grubs, naturally are very small when first hatched and are white in color. After feeding they become somewhat maggotlike in general appearance, being nearly cylindrical, fleshy, distinctly wrinkled, more or less curved in outline, and not more than one-fourth of an inch long and usually less.

By the time the grub has become full grown it has eaten out in the seed contents a cell in which to transform to the pupa or chrysalis. Before transforming it secretes a substance which hardens into a white, filmy cell about itself, and this serves to protect the helpless

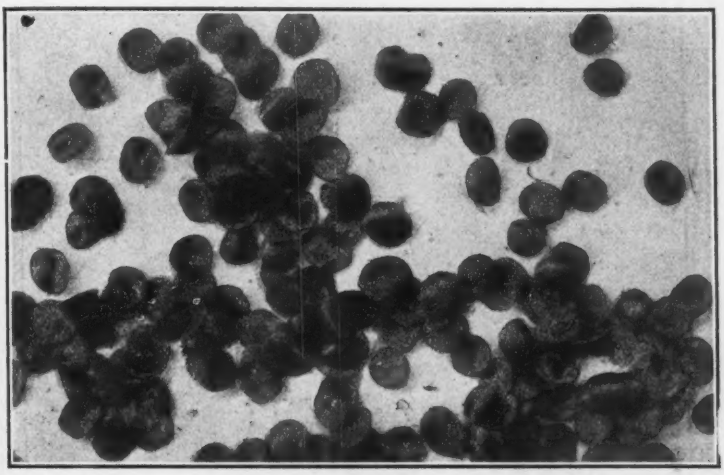

FIG. 6.—In escaping from beans, peas, or cowpeas, or any host, weevils leave behind them the small round holes familiar to all. In making these holes they use their jaws to cut around the dark spots shown in Figure 5 and then push away the circular flap of skin just as one opens a tin can of preserved fruit with a can opener. These circular bits of skin, shown above, about four times natural size, may be found among the seeds

pupa while the changes to the adult are taking place. For the general shape and appearance of the grub and pupa see Figures 10, 12, and 13, *b* and *c*, and Figure 17, *c*. The pupal cells are shown in Figure 22. For the general life cycle see Figure 3.

THE PEA WEEVIL[8]

The pea weevil is the most serious enemy of the field or garden pea. It now occurs over almost the entire globe wherever peas are cultivated. Continuous cropping of land to peas naturally leads to a constant increase in the number of pea weevils.

Garden peas grown almost anywhere in the United States are apt to be badly infested, but because they are eaten green before the infestations have progressed the sale of the peas is not affected.

[8] *Bruchus pisorum* Linnaeus.

Serious damage to garden peas in Pennsylvania, New Jersey, and southern New York was caused as early as 1748, and nearly all growers of garden peas are familiar with the exit holes that are made by the insects in dried seed. (Fig. 11.)

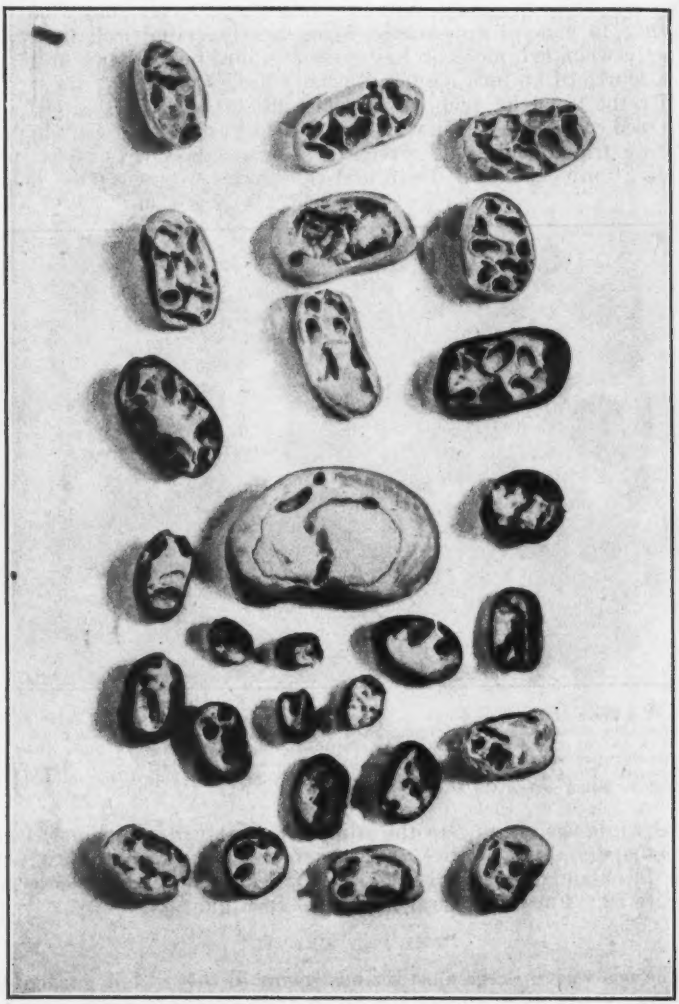

FIG. 7.—Various types of beans and cowpeas cut lengthwise to show how severely they may be damaged by bean and cowpea weevil grubs. Such beans and cowpeas are not fit for human food. Slightly enlarged

The pea weevil is most serious as a pest of the dried seed peas, either of the garden or field varieties. The infestation in field peas at harvest time, even in our more northern States, is known to amount at times to as high as 80 or 90 per cent of the crop in certain fields, although the average infestation for the community may not exceed

from 4 to 10 per cent. As the development of one weevil usually ruins that seed for planting purposes it is easy to understand the importance of control measures.

The pea weevil is a small grayish or brownish-gray beetle about a fifth of an inch long and marked with black and white spots as shown in Figure 10. The short line to the right of *a* in the illustration gives the actual length of the beetle. The adults appear on

FIG. 8.—Leguminous crops may be reduced to a powder by the continued feeding of weevil grubs. In the bottom of sacks or boxes in which weevily beans or cowpeas are held for a long time one finds quantities of dead weevils and the powdered remains of the seeds such as are shown above. About natural size

the vines when the peas come into bloom. They are said to feed principally on the petals of the pea flowers and on the succulent tissues of the stems and pods as shown in Figure 9. While they eat holes in the petals and gnaw out long narrow slits in the stems, they do not appear to damage the plants materially, as the damaged flowers produce normal pods and the slits in the stems soon heal over and do not cause wilting.

The adults show a strong tendency to remain dormant during the season of the year when growing peas are not available for attack. Thus while certain beetles having access to pea plants lived only four or five weeks, others were found alive in dried seeds 14 months after the seeds were gathered. The female weevils lay their yellowish eggs singly upon the surface of the pods to which they attach them with a peculiar viscid secretion. The young grub upon hatching gnaws through the pod and burrows into the seed, where it does practically all its feeding. While as many as six young grubs have been found in single seeds, it is seldom that more than one matures and emerges. (Fig. 11.)

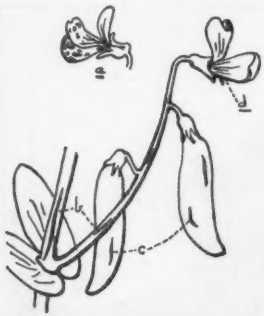

FIG. 9.—Plant of garden pea showing at *a*, holes in blossom where pea weevil beetles have fed; at *b*, slits in stem; and at *c*, cuts in pods made by the feeding beetles. The beetle finds its favorite shelter at *d*. (Skaife.)

The length of time required for the eggs to hatch and for the grub or larva to mature into the adult of the next generation varies with the climate. In the District of Columbia adults have appeared as early as July 21. Others have been reared as late as the middle of August. A very considerable portion of the beetles mature and leave the seeds in the latter part of the summer in the latitude of Washington, D. C., but farther north and in higher altitudes the adults remain in the peas until the following spring, when they emerge in storage or are planted with the seed, or they emerge from the seed by harvest time and seek hibernating quarters. Adults sometimes emerge in such numbers during the threshing of the peas in certain northern field infestations as seriously to annoy the workmen. It is largely in the adult stage that the weevil passes the winter, hibernating either in secluded spots in fields or buildings or in the pea seed itself. The pea weevil has only one generation a year and can not reproduce in dried peas.

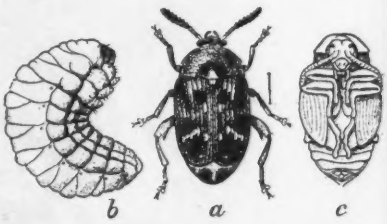

FIG. 10.—Pea weevil: *a*, Beetle; *b*, larva or grub; *c*, pupa. The line to the right of the adult (*a*) represents the actual length of the beetle, and the sizes of the larva and pupa are in proportion. (Chittenden.)

THE COMMON BEAN WEEVIL[9]

The common bean weevil is one of the most formidable enemies to the culture of beans in the United States as well as in many other countries. It occurs in nearly every State and the Territory of Hawaii, and is generally distributed throughout Mexico, Central America, and South America. It has been found in beans imported from southern Europe, Persia, India, China, Algeria, South Africa, Madeira, the Azores, and the Canary Islands. Commerce has carried it to all the larger markets of the world. So severe is its attack in the warmer sections of this country that dried beans for seed and for food are grown mostly in the more northern States and California.

[9] *Bruchus obtectus* Say.

In the coastal region of the Middle Atlantic States and farther south bean growing is made very difficult, if not rendered unprofitable, by the unmolested increase of the bean weevil.

The bean weevil is smaller than the pea weevil, being only about an eighth of an inch long, and shaped and marked as illustrated in Figure 12. The adult, or beetle, is so coated with fine hairs that it appears brownish gray or olive color. Unlike the pea weevil, the bean weevil not only can develop in growing beans in the field, but also can breed generation after generation in dried beans in storage.

The adults may live as long as nine weeks, though usually two weeks represents their more normal length of life during the active season. Of course, adults may remain alive in a dormant condition for several months in dried seeds during cold weather.

The female weevils may fly from storage quarters early in summer and from then on may be found upon the bean plants. While the weevils lay their eggs in largest numbers through cracks in the pod that develop during the drying out of the pod, the female has been observed to gnaw holes in green pods and to lay her eggs through such holes. Eggs are never glued to the outside of the pod as is the habit of several other species of bean and pea weevil. In storage the eggs are laid singly

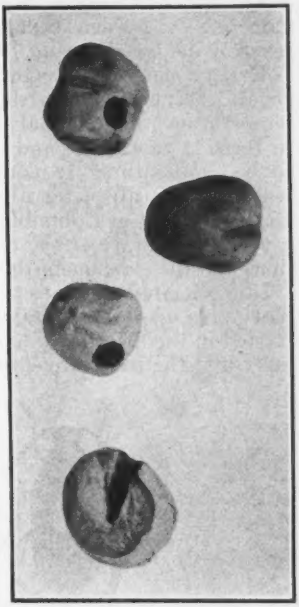

FIG. 11.—Garden peas showing exit hole of the pea weevil. Note that only one weevil develops in a single pea. One seed has been sectioned to show cavity made by grub. Twice natural size

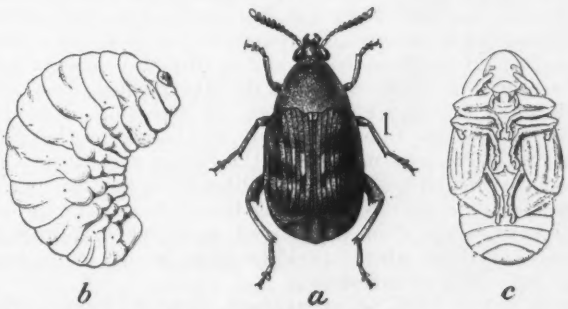

FIG. 12.—Common bean weevil: *a*, Beetle; *b*, larva or grub; *c*, pupa. The short line to right of the beetle (*a*) represents its real length. (Chittenden)

and loosely (i. e., unattached) among the seeds. As many as 59 eggs may be laid by a single female in one day, and a total of 209 eggs

during her life.[10] As many as 67 eggs have been found laid through a crack in a bean pod.

As many as 28 weevil grubs have been found in a single bean. All varieties of garden beans are attacked, even Lima beans being severely damaged during 1920 and 1921 in New England.

Experiments have demonstrated that the eggs of the bean weevil require from 5 days in the hottest weather to 20 days at a cooler temperature to hatch, and that the larvæ or grubs become full grown in from 11 to 42 days and the pupæ in from 5 to 18 days, according to the temperature. It requires 21 to 80 days at least, according to the season and locality, for a generation of the bean weevil to develop. In the District of Columbia there may be as many as six generations a year. The warmer the climate the greater the number of generations and the consequent damage done by the grubs.

In a climate similar to that of the District of Columbia and adjacent parts of Maryland and Virginia, adults of the first generation started in the field begin to emerge as early as October. If the fall is early and the seeds are stored in a cold place no adults may emerge before the following spring. If seeds are stored in a warm place, adults may emerge at any time during the winter. After emergence in storage the adult females lay eggs either on the beans or on the sides of the receptacles in which the seeds are stored.

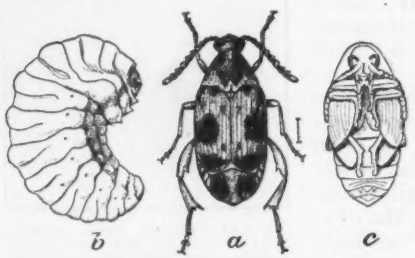

FIG. 13.—Southern cowpea weevil: *a*, Beetle; *b*, larva or grub; *c*, pupa. Six times natural size. (Chittenden)

SOUTHERN COWPEA WEEVIL[11]

The southern cowpea weevil is a major pest of cowpeas in the United States. The female is about one-eighth of an inch long and is distinguished by four black spots upon the wing covers as shown in Figure 13. In 1885 this species was found swarming on black-eyed cowpeas from Texas exhibited at the Atlanta Cotton Exposition. Since then it has spread throughout the Southern States, California, and as far north as Iowa, and is probably present wherever cowpeas are grown. The cowpea is its favorite host food, although peas and beans are attacked. (Figs. 14 and 15.) While female weevils may lay eggs upon the pods and seeds in the field, and hardly a crop of cowpeas matures in the South without an abundant infestation, this weevil breeds most prolifically in dry seeds in storage. It does not lay its eggs loosely among the seeds as does the common bean weevil, but glues them to the seed, as shown in Figure 15, and the presence of these white specklike eggs in any consignment is always an indication of infestation.

The adult weevil lives, on an average, about 15 days. While the average number of eggs laid per female in certain experiments was 82, as many as 196 eggs were laid by one female. Usually the largest

[10] Records of A. O. Larson and C. K. Fisher. [11] *Bruchus quadrimaculatus* Fabricius.

numbers of eggs are laid during the first few days of adult life. One female weevil laid 22, 15, 15, 14, 6, 13, 2, 11, 6, 0, 0, and 2 eggs, respectively, on the first 12 days after leaving the seed in which she developed. Death soon follows the completion of egg laying. Eggs hatch in from 4 to 6 days during warm summer weather. During the cold winter weather in Texas eggs require from 25 to 37 days for development. The percentage of eggs that hatch in winter is very small while that in summer is very high. The length of the larval stage varies from 9 days to more than 8 months. During warm summer weather from 17 to 22 days is usually required. Larvae emerging from eggs laid late in the fall require long periods for development and pass the winter as dormant grubs within seeds in cold warehouses. Taking the egg, larval, and pupal stages into consideration, it is safe to say that development requires from 30 to 48 days during warm weather.

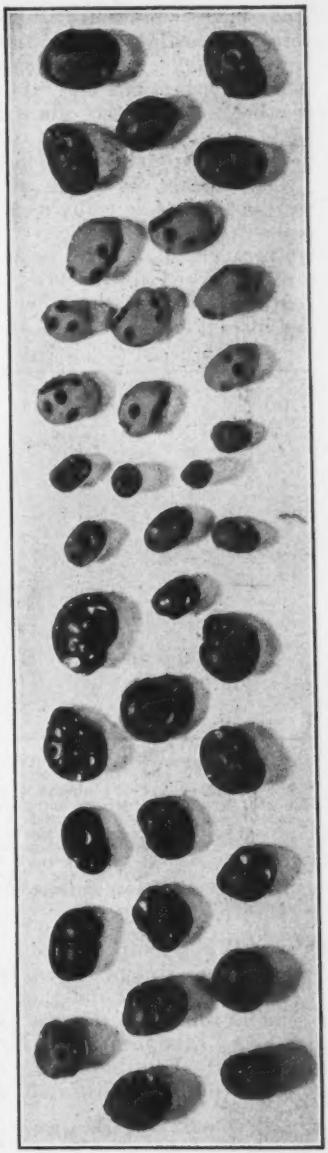

FIG. 14.—Different varieties of cowpeas showing infestation by southern cowpea weevil. Seed about natural size; the white specks on the seeds are the eggs of the weevil

THE COWPEA WEEVIL [12]

The cowpea weevil (fig. 17) is a foreign species first described from China. It has been reported from every continent and is likely to be found in any commercial center. From 1898 to 1911 it was known to be well distributed and often abundant throughout the Gulf Coast States and even as far north as Washington, D. C. It is now a pest of minor importance in the United States, where it has not been observed for some years. Although it prefers cowpeas, it may attack the common pea, pigeon pea, lentil, chick pea, mung bean, and the common white bean.

The adult weevil is about an eighth of an inch long and may be distinguished from other weevils discussed in this bulletin by the elevated ivory-like spots near the middle of the body, as shown in Figure 17. Its

[12] *Bruchus chinensis* Linnaeus.

biology [13] is similar to that of the southern cowpea weevil. During very hot weather a generation may mature in 21 days (egg, 4 days; larva, 13 days; pupa stage, 4 days). This period is lengthened by cooler weather and may approximate 3 or 4 months during winter weather. This insect glues its whitish eggs to the surface of the seeds, as does the southern cowpea weevil, and is capable of breeding indefinitely in dried seeds in storage.

The adults live on an average 5 or 6 days during the hottest weather and to as many as 40 days during the winter months in the Gulf Coast States. Activity is likely to cease entirely at a mean temperature of 50° F., or below, when the insects will seem dead to all outward appearances, and only resume activity upon the appearance of warm weather. While the immature stage may be passed in as few as 16 or 17 days, 21 days is closer to the normal time required during hot summer weather. The longest period for larval development yet recorded is 88 days, from December to March, in Texas, when the temperature ranged from 22° to 86°. There may be from 8 to 10 generations a year in the Gulf Coast States.

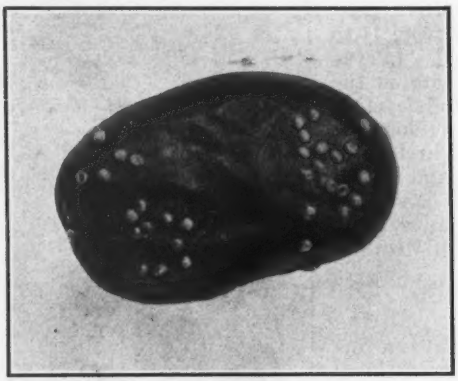

FIG. 15.—A cowpea seed showing eggs of the southern cowpea weevil. The eggs of bean and pea weevils vary in shape but are always small, ranging in length from one-fiftieth to one twenty-fifth of an inch. They are white or whitish, and may be laid anywhere upon the outside of the seed, as indicated here, or in cavities in the seed made by a previous generation of grubs, or on sides of containers such as burlap sacks, barrels, etc. The eggs can be distinctly seen on seeds, as tiny white specks. Five times natural size

THE LENTIL WEEVIL [14]

The lentil weevil is not known to be established in this country at the present time, although it has been found repeatedly in imported lentils from Europe. It is an enemy of the lentil crop in middle and southern Europe, Egypt, and Syria. While lentil growing is on the increase in this country, it is hoped to keep this pest from becoming established in North America.

The lentil weevil, only one of which matures in a single seed, resembles somewhat the pea weevil but is only about an eighth of an inch long. Like the pea and broad-bean weevils, it has but one generation a year. Lentils showing the emergence holes and injury caused by this weevil are illustrated in Figure 18.

THE MEXICAN BEAN WEEVIL [15]

The Mexican bean weevil is an inhabitant of South and Central America and is occasionally found at our Pacific and Atlantic ports,

[13] CHITTENDEN, F. H. THE COWPEA WEEVIL. U. S. Dept. Agr., Bur. Ent. Bul. 96, Pt. VI, 12 pp., illus., 1912.

[14] *Bruchus lentis* Boheman.

[15] *Spermophagus pectoralis* Say.

infesting beans imported from these countries. It attacks beans and cowpeas. It breeds continuously in dried seeds and is capable of being as injurious as the common bean weevil, as indicated by the five small beans affected by this pest, shown at the bottom of Figure 1. For the size, shape, and coloration of this insect, see Figure 19. The adult lays her eggs upon the seeds, to which they are stuck by a cement similar to that used by the southern cowpea weevil. (Fig. 15.) While occasionally intercepted at ports of entry for many years past, this species does not appear to have become established in the United States.

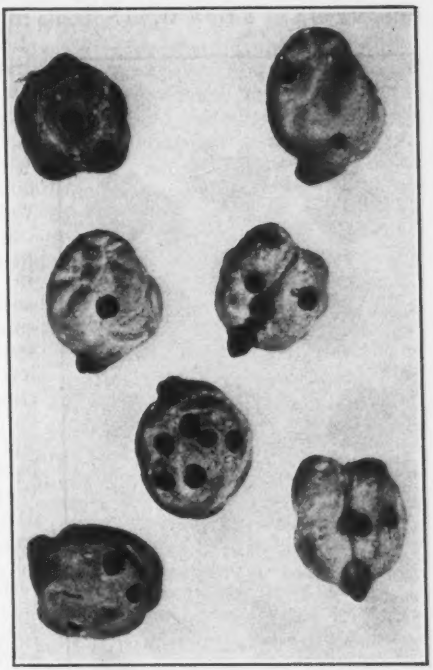

FIG. 16.—Chick-peas affected by the southern cowpea weevil. Compare these with the two-sectioned chick-peas at the bottom of Figure 22. Twice natural size

THE BROAD-BEAN WEEVIL [16]

The broad-bean weevil closely resembles the common pea weevil, being about the same size, one-fifth of an inch long, and of similar appearance. It can, however, be readily distinguished by its much narrower thorax and fainter markings, as a comparison of Figures 20 and 10 will show.

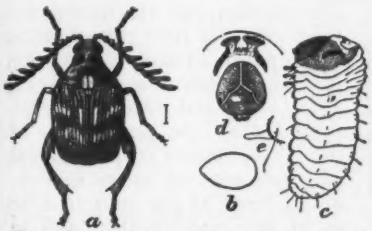

FIG. 17.—Cowpea weevil: *a*, Adult male; *b*, egg; *c*, postembryonic larva; *d*, front view of head of same; *e*, thoracic leg of same; *a*, six times natural size; *b–e*, more enlarged. (Chittenden)

The broad-bean weevil (fig. 20), sometimes called the European bean weevil, is common and destructive in Europe and North Africa. While it feeds upon various sorts of beans and peas, it appears to prefer the broad or Windsor beans. (Fig. 21.) Although it has been found from Canada to Texas in Windsor beans imported into various parts of this country, the first discovery of its definite establishment in the United States was made in 1909 at San Luis Obispo,

[16] *Bruchus rufimanus* Boheman.

Calif., where it was injuring the broad or Windsor bean (*Vicia faba*) grown for stock feed.

Since then, and up to 1920, it has spread to include the coastal counties of California, from Sonoma to San Luis Obispo, besides San Benito, Santa Clara, Alameda, San Joaquin, Sacramento, Yolo, and Napa. Practically every broad bean entering a New York warehouse is more or less damaged by this pest. A single grub in its development consumes approximately 3 per cent of the bean. Sometimes as many as six weevils develop in a single bean. Beside the actual amount of seed consumed, there must be considered the frass of the insect left behind in the seed, and this still further reduces the value of the crop. It has been stated that of the entire broad-bean crop of California for the years 1916, 1917, and 1918, 31.21, 18.01, and 43.08 per cent, respectively, were above the 15 per cent limit of weevil infestation allowed by the Federal pure food law, and therefore could not be shipped unless hand picked. In 1916 the average percentage of infestation for the entire 1916 crop in the Halfmoon and Gilroy regions was above the 15 per cent limit, while the same was true for the Sacramento and Halfmoon districts for the 1918 crop. After a campaign of seed fumigation in San Mateo County during 1918, 1919, and 1920 it was reported that the percentage of the broad-bean crop infested 15.1 per cent or more was reduced from 43 per cent in 1918 to 21 per cent in 1919 and to 17.8 in 1920. Since beans uninfested, or infested less than 15 per cent, were worth during these years from 5 to 6 cents per pound, and others only 2¼ to 3 cents, it is easy to appreciate the dollars and cents value of concerted action among growers in applying cheap, but effective, remedial measures.

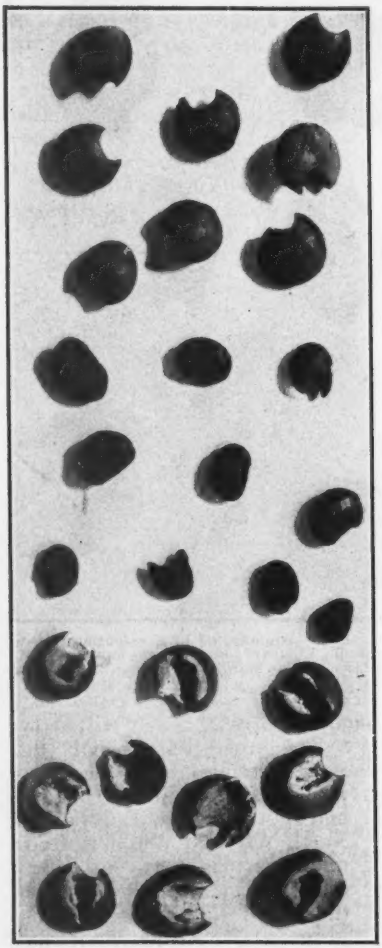

FIG. 18.—Lentils of two varieties showing injury by the lentil weevil. While only one lentil weevil matures in a single seed, it is capable of practically destroying that seed, as indicated by the sectioned seeds at the bottom of the illustration. Somewhat enlarged

The following biologic facts are taken from a report of experiments conducted at Alhambra, Calif.[17] The egg stage lasts from 9 to 18 days, the larva stage from 10 to 15 weeks, the pupa stage from 7 to 16 days, and the beetle lives from 1 to 8 months. The eggs are laid on the green bean pods in the field from the middle of March to the middle of May; the larvæ reach maturity from August to October, while the adults can be found from August to the following June. The broad-bean weevil has but one generation each year and can not start new generations in dried seed in storage. That is, such beetles as emerge from the seeds in storage have developed exclusively from eggs laid in the field upon the green pods and can do no further injury in warehouses.

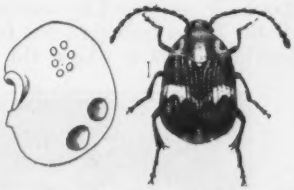

FIG. 19.—Mexican bean weevil: Adult weevil with line to left indicating actual length. Infested bean to left showing two emergence holes and six eggs. (Chittenden)

WHY WEEVILS LIMIT ACREAGE PLANTED TO CERTAIN LEGUMINOUS FOOD CROPS

It has been pointed out already that infestation nearly always takes place in the field while the crop is maturing. With garden or Canada peas, lentils, and broad or Windsor beans infested with the pea weevil, the lentil weevil, and the broad-bean weevil, respectively, this is always the case, for these weevils never breed in dried seeds. Other species that breed in dried seeds, as well as in the field, may spread in storage to uninfested seeds and badly infest them. It is generally known that the colder the winters the shorter the growing season and the fewer the bean and pea weevils that survive the cold of winter and are ready to fly to the fields to start the infestation of the growing crop by laying eggs upon the pods. The farther south one goes the more mild the winters become, the longer the growing season, and the greater the number of weevils that can live through the winter.

FIG. 20.—Adult of the broad-bean weevil. Enlarged six times. (Chittenden)

As far south as the District of Columbia and the adjacent tidewater country of adjoining States, therefore, overwintering weevils attack the beans and peas in large numbers and succeed in years favorable for them in laying so many eggs upon the pods that each developing bean becomes affected and often may support as many as 20 to 28 weevil grubs. Because of the long, warm falls and the length of time the plants are allowed to remain in the field after the crop has ripened, either standing in the ground or pulled and stacked, these grubs are given every opportunity to develop into adults or at least to become very well grown in an unusually large number of cases, and therefore they cause greater damage than do weevils in bean fields farther north. Thus beans grown in latitudes south of New York City, except in higher altitudes, as in the

[17] CAMPBELL, R. E. THE BROAD-BEAN WEEVIL. U. S. Dept. Agr. Bul. 807. 22 pp., illus., 1920.

mountainous regions of the Alleghenies, become more infested than those grown north of that latitude. As weevils in beans are not killed so easily as are many other insects, and as their presence in numbers in beans is objectionable whether beans are grown for food or for planting, even when the grubs have been killed (fig. 22), the growing of beans on a commercial scale for dried seeds has largely been given up in our more southern latitudes. This explains the question often asked why beans and peas grown in portions of California, Michigan, New York, Washington, Oregon, or Idaho, or even in Canada, find their way into our southern markets, which one would expect should be supplied by southern-grown beans and peas. Practically all the dried beans grown for seed and for food are grown in these Northern States where the bean weevils are not able, because of

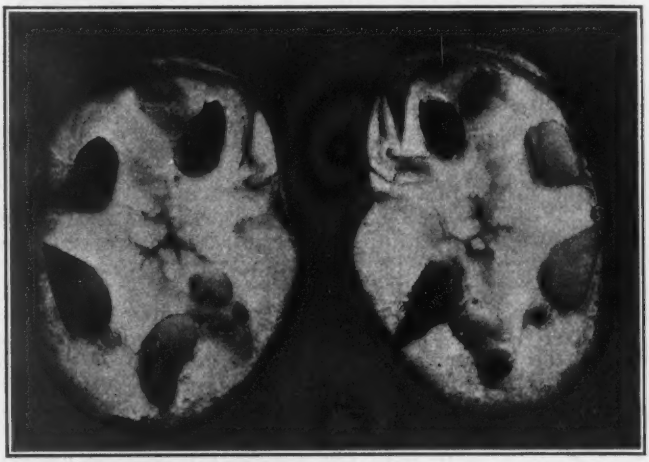

FIG. 21.—A broad, horse, or Windsor bean, cut open to show the damage caused by grubs of the broad-bean weevil. Only one generation of this weevil occurs each year. As each cavity represents the feeding of one grub, this bean is badly affected. Considerably enlarged

climatic checks, to cause so much damage. Of course weevils do not affect the growing beans to be eaten green, as string beans or green shelled beans, for such beans are not, at the time of gathering, infested; or if infested, the grubs are too small to interfere with their value as food.

GERMINATION AFFECTED BY WEEVIL ATTACK

The germination of beans, peas, and cowpeas is likely to be seriously affected by the development of weevil larvæ. If the embryo is destroyed by the larva, or if too much of the bean substance is eaten, the seeds can not grow.

Beans as badly infested as those shown in Figures 1, 7, and 23 are worthless for planting. As the young bean or pea plant depends upon the food stored in the seed to give it its first start, the destruc-

tion of any portion of the seed by weevils lessens by so much the vigor of the plant. In one experiment on record, only 50 per cent of infested beans germinated, and of these 30 per cent were so badly injured that they could not develop into normal plants. The smaller the seed, the greater proportional damage a single weevil grub can cause. One grub ruins a small cowpea seed (fig. 14) or a lentil (fig. 18), whereas it would not so seriously affect a large seed like the Lima bean. The germination of broad beans infested with 1, 2, 3, and 4 or 5 broad-bean weevils was found to be reduced from a normal of 95.7 to 82.7, 72.7, 71.1, and 69.6, respectively. In examining 50 garden peas infested by the pea weevil, 33 were found with the embryo wholly or partially destroyed, and in another case only 69 out of 275 infested peas had undamaged embryos or germs.

FIG. 22.—Beans (six upper seeds) and chick-peas (two lower seeds). The skin of the beans has been removed to reveal the cavities eaten out by the common bean weevil grubs. The grubs have been killed by fumigation and have turned black. Note the white paperlike cell or cocoon about each of the grubs. The chick-peas have been cut open to show how the larvae of the southern cowpea weevil can burrow to the very center of the seed. Slightly enlarged

HEATING DUE TO INFESTATION

It is a well-known fact that beans and peas, as well as grains, will heat if insects become sufficiently abundant in them. In bean warehouses where the seeds are stacked, as shown in Figures 26 and 27, centers of weevil infestation can be detected by walking past the tiers of sacks and allowing the hand to pass over the sacks. Experience soon makes it easy to detect heating sacks. Heating seeds also produce an odor quickly detected by experienced persons when they enter a warehouse after it has been closed for a few hours.

The ability of bean and pea weevils to produce heating of the seeds is of great importance. Were it not for this ability, owners could rest assured that if warehouses were open to outdoor temperatures below 50° F. no injury from weevils would take place. Certain weevils develop most quickly when the temperature ranges between 75° and 95°, and egg laying is greatly stimulated by these higher temperatures. At temperatures ranging from 75° to 95° development of the southern cowpea weevil has been known to be completed in as few days as 18; hence heating caused by weevil infestation, with the accompanying increase in moisture content of the seeds, may

result in an outbreak of weevils at a season of the year when least expected. The temperature of a 240-pound sack of chick-peas infested by the southern cowpea weevil may be raised by infestation to at least 103°. It is not uncommon in some warehouses to find a considerable number of sacks the temperature of which has been raised to over 80° or 90°. In one instance, when the daily maximum temperatures ranged between 50° and 58°, sacks within 2 feet of an open window registered 102°. The temperature in the spaces between heating sacks was raised in this warehouse from 58° to a minimum of 70° and a maximum of 78°. At 58° adult weevils were too cold to migrate, but at 70° to 78° they were very active and were spreading from heating sacks to surrounding sacks and laying eggs upon previously uninfested seeds.

This effect of heating, due to infestation, upon spread of injury from sack to sack, to say nothing of increase in infestation within the individual sacks during cold weather, should be understood by those holding beans and peas, else a genuine loss will come upon them

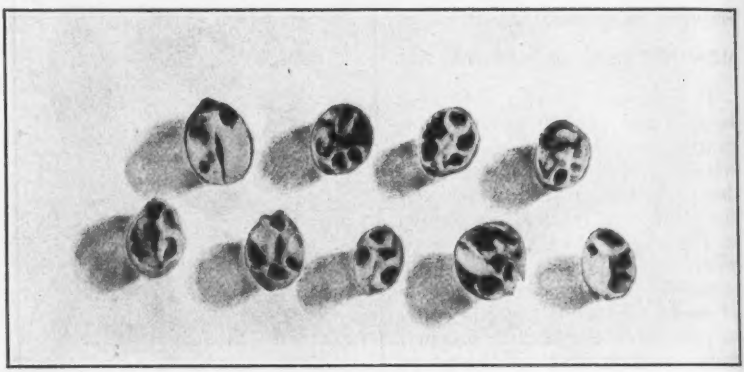

FIG. 23.—Navy beans cut crosswise to prove how the common bean weevil can ruin seeds for eating or planting. About natural size

unawares. Fumigation with hydrocyanic-acid gas (p. 25) kills the insects, reduces the temperature to normal, and stops spread. Fumigation with any efficient fumigant will doubtless do the same.

REMEDIES

No group of seed pests can be more easily controlled in storage than pea and bean weevils. Once seeds are dried and housed they can be protected from destruction. Owners should watch their crop and apply treatment at the first sign of infestation. Any remedy that lessens the number of weevils present in the field has a direct effect upon the number of weevils to be fought in storage, and vice versa.

PLANTING OF INFESTED SEEDS WILL NOT CAUSE AN INFESTED CROP

Although it is better not to plant infested beans or peas because the weevils have injured the food content of the seed upon which the

seedling plant depends for its first rapid growth, the planting of seeds containing live weevils will not cause the following ripening crop to become infested. The old belief that weevils emerging from weevily seeds that have been planted can live long periods in the bean field or garden and be ready to infest the ripening crop has been proved false. Experiments have also proved that the scattered beans left exposed on the ground at harvest time are not a source of infestation from the standpoint of the next year's crop.

REMOVAL OF BREEDING PLACES IMPORTANT

The removal of dried beans and peas and their straw or vines is very important. Thus in bean-growing regions of California it has been proved that bean weevils will multiply for several years in piles of bean straw on bean plantations and that from such piles weevils fly to the ripening beans and cowpeas and infest the new crop. Small quantities or beans in warehouses, barns, attics, or any other storage place may be the source of thousands of weevils which fly to the fields and gardens to infest the new crop. In fact, it is now believed that this source of infestation is the only one, and that if bean growers will cooperate intelligently and thoroughly in the destruction of insects in their storage places, no infestation of the crop will occur. Many farmers and gardeners along the Atlantic seaboard have weevily beans in their storerooms which breed weevils throughout the summer following the fall when the seeds were harvested, and from these seeds enough weevils fly to the near-by gardens and fields to cause the new crop of beans to become weevily.

HARVEST, THRESH OR SHELL, AND SACK AS SOON AS POSSIBLE

Because some adult weevils emerge in the late summer and fall, according to the latitude, leguminous crops subject to weevil attack should be harvested as soon as possible after reaching maturity. The seed should be threshed or shelled at the earliest possible moment in order that the seeds may be more easily and cheaply treated to keep the weevil grubs from feeding and maturing. Storing in the pod does not confine the weevils. The grubs continue their development and transform to the adult in the unshelled as well as in the shelled seeds. Adult weevils can gnaw their way out of dried pods, as shown by the exit holes in the pods of Figures 24 and 25. The weevils in large bulks of unthreshed or unshelled beans or peas can not be satisfactorily treated. There is only one answer to the often-asked question, "Is it better to store beans or peas in the pod or shelled?" Shell the seeds and treat them if you suspect weevil injury.

FUMIGATION

Weevils may be killed in storage by fumigation with carbon disulphide, carbon tetrachloride, or hydrocyanic-acid gas.[18]

CARBON DISULPHIDE

Fumigation with carbon disulphide (CS_2) is one of the simplest remedies for weevils. The nature and use of this fumigant is dis-

[18] It seems probable at this time (January, 1930) that ethylene oxide, either alone or in combination with carbon dioxide, will prove an effective fumigant for beans, peas, and cowpeas. The gas, if used as directed, is noninflammable and nonexplosive. Particulars regarding its use will be furnished on request.

cussed in Farmers Bulletin 799, which can be had upon request from the United States Department of Agriculture. Carbon disulphide is purchased as a liquid in iron drums or tin cans and weighs about 10½ pounds per gallon at ordinary temperatures. Upon exposure

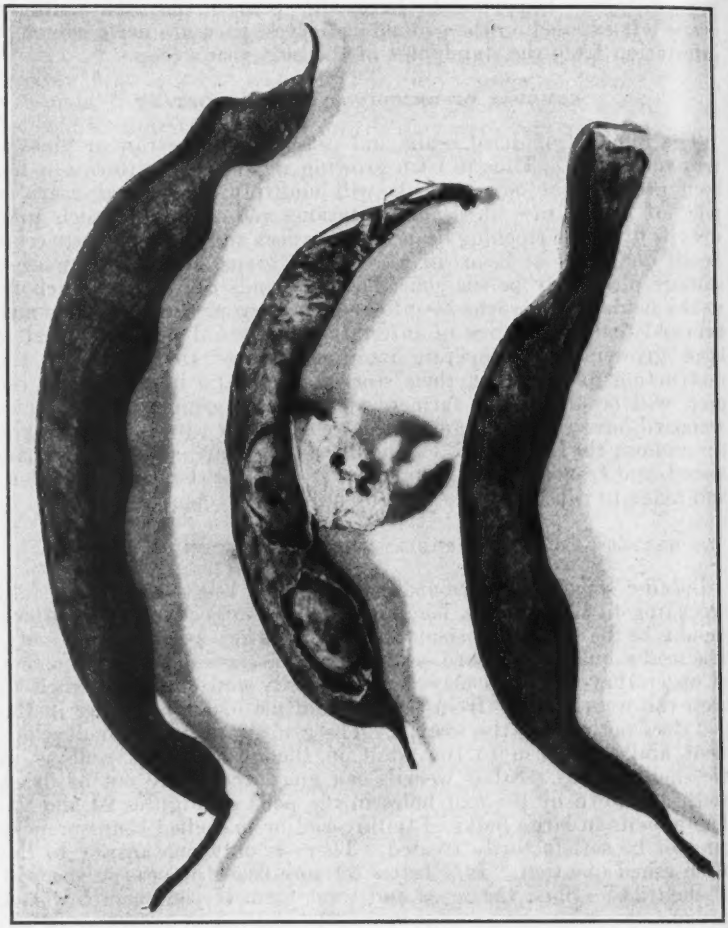

FIG. 24.—Storing beans, peas, or cowpeas in the pod will not prevent the weevils from ruining the beans if they are already in the seeds. Neither will it prevent them from emerging, as indicated by the holes they have made in the pods shown above in making their escape from the seeds. One pod has been cut to expose the infested beans within. Work of the common bean weevil. One and one-fourth times natural size

to air the liquid evaporates or volatilizes, forming a foul-smelling gas that is about twice as heavy as air. Because the gas is heavier than air and evaporates more quickly if a larger surface of the liquid is exposed to the air, the liquid should be poured out into shallow

pie tins or similar shallow dishes and placed upon the top of the seeds to be fumigated. Seeds will not be injured or poisoned if the liquid is sprinkled or poured directly upon them. In estimating the quantity of carbon disulphide needed, the volume of cubic space in the container in which the fumigation is done should always be considered—not the amount of space occupied by the seeds.

If used according to directions, carbon disulphide will not injure the germination of thoroughly dry seeds or affect their value for food. The disagreeable odor passes away after seeds fumigated have been aired. While carbon disulphide has become a standard fumigant and has been used for years without trouble by many individuals and firms, it is always timely to call attention to the fact that the gas is explosive and inflammable if fire is brought close to it during fumigation. Fire, as used here, includes even a lighted cigar, lighted lantern, or the spark from an electric fixture.

Seeds to be fumigated should be placed in an air-tight container. This may be a tin pail, wash boiler, barrel lined with heavy paper, galvanized-iron garbage can, or other receptacle, or a specially constructed fumigation box or room, according to the quantity of seed to be fumigated. One of the simplest satisfactory containers for fumigation on a small scale is a water-tight barrel. The tighter the receptacle the better the results. Satisfactory results can not be secured if fumigation is attempted in a room full of cracks.

Carbon disulphide should be used at the rate of from 4 to 20 pounds to each 1,000 cubic feet of space to be fumigated, the quantity to be used varying with the tightness of the container and the temperature. The liquid should be poured over the top of the seeds to be fumigated or poured into shallow dishes set on top of the seeds. It quickly vaporizes, and as the gas is heavier than air, it sinks to the bottom of the container, filling all the air spaces. Fumigation should continue from 24 to 48 hours, although most of the actual killing is done during the first 6 to 8 hours of exposure. It is always better to use too much rather than too little carbon disulphide.

FIG. 25.—Pod of field pea showing exit hole of cowpea weevil. This pod was taken from a bale of field-pea hay grown in Florida and indicates that even field-pea hay grown only for cattle feed may be instrumental in offsetting community cooperation to lessen weevil injury. One and one-fourth times natural size

Beans, cowpeas, and peas can be stored and fumigated conveniently in water-tight barrels. These should be filled to within a few inches of the top with seeds. In fumigating, pour one-half cup or more of carbon disulphide on the seeds and then cover the top of the barrel with a double thickness of heavy wrapping paper tied tight around the top, or several sacks weighted down with boards. A wooden cover is also useful in keeping in the fumes.

Fumigation with carbon disulphide to give the best results should be carried on at or above a temperature of 75° F. It is not effective at temperatures below 60°. After fumigation the seeds should be examined occasionally and given a second or third fumigation in case living weevils are found.

Carbon disulphide costs from 6 to 25 cents a pound. It is cheapest when purchased in 55-gallon drums (550 pounds.) The cost is greatest when the liquid is bought in 1-pound cans and then may range from 25 to 40 cents per pound.

To these prices must be added transportation costs. Farmers throughout the country can purchase carbon disulphide of local drug stores, but prices under such conditions often are exorbitant. County agents, boards of trade, or other public-spirited local organizations can purchase carbon disulphide and furnish it at cost to farmers in the vicinity. This has been done in certain southern towns with the result that farmers have secured carbon disulphide of excellent quality [19] at lowest price. If local firms can not supply carbon disulphide, the names of firms in a position to fill orders may be obtained upon application to the Bureau of Entomology, United States Department of Agriculture.

Remember, if you do not get results with carbon disulphide the trouble is (1) with the way you apply it; (2) your container is not tight; (3) your dealer has sold you poor liquid; or (4) you have fumigated when it is so cold that no one can get good results.

Remember that large business firms and many farmers use carbon disulphide successfully and that its use on farms is on the steady increase. Nothing speaks better for any control measure than its steady use by successful business men, no matter whether they are farmers or seed brokers.

CARBON TETRACHLORIDE

Carbon tetrachloride (CCl_4) is a fumigant that has been used as a substitute for carbon disulphide in fumigation work, since it has the advantage over carbon disulphide of being noninflammable. When pure, carbon tetrachloride is a thin, transparent, colorless liquid, with a pungent, aromatic odor. Except for being noninflammable, it is similar to carbon disulphide in all essential features, from the standpoint of application. It costs from 11 to 60 cents a pound. It is not likely to take the place of carbon disulphide because of its inferior killing qualities and its somewhat greater cost per pound. Its great advantage is its noninflammability.

If carbon tetrachloride can not be had from local firms the names of firms supplying this chemical may be obtained upon application

[19] Unscrupulous dealers sometimes sell inferior lots of carbon disulphide. Dealers selling liquid containing less than 98 to 99 per cent actual CS_2 violate the Federal insecticide act and are liable to prosecution in Federal courts.

to the Bureau of Entomology, United States Department of Agriculture.

HYDROCYANIC-ACID GAS

Fumigation with hydrocyanic-acid gas is recommended when large quantities of beans, peas, cowpeas, or chick-peas are found infested with weevils. The seeds must be in sacks and so stacked that the gas can reach several sides or portions of the sacks. Chick-peas stored in 240-pound sacks, and stacked as shown in Figures 26 and 27, were almost perfectly protected by fumigation. It has been found in the fumigation of warehouses, sometimes as large as 150 by 150 by 20 feet, and containing as many as thirty thousand 240-pound sacks of chick-peas, that hydrocyanic-acid gas can be depended upon to eliminate infestations almost completely. Fumigation with this gas for the

FIG. 26.—Carload lots of 240-pound sacks of chick-peas as stacked in badly infested warehouse. Samples taken throughout length of sack proved that hydrocyanic-acid gas penetrated to the very center and that infestations were killed

control of bean and pea weevils has proved so satisfactory that its use is now an established practice with certain firms. For seed so stored the dosage should be increased from the normal dosage of 1 pound of sodium cyanide for each 1,000 cubic feet of space to be fumigated to 2½ pounds per 1,000 cubic feet. Since it is extremely poisonous, hydrocyanic-acid gas should be used only by responsible persons who are thoroughly informed on the subject of fumigation. As the gas is lighter than air and readily escapes, does not injure the seeds for planting or for food, injures no warehouse equipment, and is non-inflammable when mixed with air in the proportions used in fumigation, it lends itself for use in almost any warehouse section if the fumigation is properly timed and supervised. Full details for fumigation with hydrocyanic-acid gas may be obtained from this department.

HEAT

Heat as a means of killing weevils in legumes is growing in favor. Small quantities of seed grown on the farm or in the town garden

can be treated by placing them in an oven after they have been spread rather thinly in shallow pans and heating them to from 120° to 145° F. for several hours. An old remedy is to dip seeds into boiling water for one minute. Holding seeds in boiling water for more than one minute will injure their value for planting purposes and immersion for even one minute has been known to affect germination. On removal they should be spread out immediately and dried rapidly.

Weevil development in large quantities of beans, peas, and cowpeas can be stopped by a process known as kiln-drying. This process consists in heating the seeds to a temperature of 120° to 145° F., or higher, while they are being passed through a machine called a drier. This treatment not only removes a portion of the moisture in the seeds but also kills all insects in them. The loss of moisture may be an item of importance if sales are made by the pound, yet investi-

FIG. 27.—Interior view of warehouse containing thirty thousand 240-pound sacks of chick-peas with a retail value of $864,000 at time of treatment. Infestations breaking out under such abnormal storage conditions were controlled by fumigation with hydrocyanic-acid gas

gators claim that seeds containing 20 per cent of moisture or less are not easily infested by weevils, hence excessive drying with the heat not only kills the weevils but renders seeds less susceptible to reinfestation.

The embryos of the common bean weevil are killed when exposed to 125.6° F. for 10 minutes; the newly hatched larvæ die in 7 minutes at 131°; full-grown larvæ in beans die in 20 minutes at 131°; and pupæ die in beans when exposed for 25 minutes at 131°. Adults are killed by a 4-minute exposure at 131°. These data can not be relied upon when large masses of seed are to be treated. The investigator who obtained them found that 9 hours were required for the center of 2 quarts of beans inclosed in a tight paper bag to reach the surrounding temperature of 131°. Cowpeas infested with the southern

cowpea weevil were not absolutely sterilized from an insect standpoint when exposed to 140° for 5 minutes, though all the weevils were killed when the seeds were exposed to this temperature for 10 minutes in an oven. These results in killing the southern cowpea weevil were secured under conditions more favorable than those likely to occur in commercial bean establishments, hence it was recommended that seeds be exposed in commercial treatment to 146° for 20 to 30 minutes. Temperatures above 150° seemed to weaken the resulting plants, but germination took place even after the seeds had been subjected to 190° for 10 minutes. Commercial coffee roasters are used by certain bean brokers for the destruction of weevils by heat. Seeds have been treated by the carload in such roasters and guaranteed to remain free from injury by bean weevils at least during transit in carload lots. A list of firms that manufacture apparatus for heating seeds will be furnished upon application. As is done in kiln-drying, the seeds should be spread out in order that all may be affected quickly and uniformly by the heat. When thus spread out an exposure to 131° for 1 hour should be sufficient.

Heat is not recommended for the control of the broad-bean weevil in broad or Windsor beans. Exposure to temperatures ranging from 120° to 140° for 5 to 40 minutes did not kill this apparently more hardy insect and the higher temperatures had an injurious effect upon germination.

COLD AND COLD STORAGE

Weevils will not feed and cause damage at low temperatures. It is not known at what temperature development ceases, but no development takes place at or below 50° F. Cowpeas can be kept free from weevils if held in storage at a temperature of 32° to 34°. It is claimed that exposure for a season at this temperature does not affect the germinating power of the seed. Investigations conducted in this bureau indicate that no stage of the common bean weevil can withstand 56 days of cold storage at 31° to 32°, although they may survive more than 66 days at 36°. The larvæ, it appears, succumb to cold-storage temperatures more readily than do pupæ or adults. The storage room should be kept as dry as possible and the seeds should be handled in sacks as in warehouses. Cowpeas held for a season at 32° to 34° were found to lose their germinating power no sooner on removal to normal temperatures than cowpeas not thus exposed to cold. Seeds removed from cold storage to warm temperatures are likely to sweat, and if care is not taken to eliminate this surface moisture by drying or proper ventilation, moldiness may result. There is some doubt as to the real need of incurring the expense of cold storage, as seeds can be protected more cheaply by fumigation under storage conditions thought by the majority of seed owners to be better for the seeds.

LIME OR DUST AS PROTECTION TO SEED

In the Southern States, where weevils cause such great injury to stored seeds, certain farmers have resorted to mixing their seed cowpeas with dry road dust or air-slaked lime. Tests prove that the storage of cowpeas with air-slaked lime at the rate of 1 part by

weight of lime to 6 to 8 parts of peas is a great help in protecting seeds. The dust or lime does not necessarily kill the weevil grubs developing in the seeds if these are already in the seeds at harvest time, but it prevents adult weevils either from emerging, or, if they succeed in emerging, from laying their eggs on the seeds for successive generations. The dust or lime, in other words, prevents continued breeding in storage. Either substance would probably be a nuisance if mixed with cowpeas intended for food if the seeds contained many emergence holes, as the lime or dust would work into these holes and be difficult to remove. If seeds are known to be free from weevils and are stored in tight barrels, bins, or other similar containers, a top layer of air-slaked lime about one-half to 1 inch thick, if maintained, will prevent weevils from gaining access from without and starting an infestation.

COMMUNITY EFFORT TOWARD CONTROL

Anyone can protect beans and peas from further weevil injury after they are once dried and in storage. If loss occurs in storage, owners have only themselves to blame, for weevils can be effectively controlled at a cost very slight as compared with the value of the seeds protected and the increased value of the seeds after thorough treatment.

But no one person can prevent his beans and peas from becoming infested while they are developing in the garden or field unless he and his neighbors are willing to get together and pledge to treat their seeds in storage and to destroy other breeding places, such as bean-straw piles. Many adult weevils fly to fields from storage bins about the time the seeds are beginning to mature. A negligent neighbor may be the cause of much neighborhood infestation by the flying of his weevils to developing crops or into warehouses.

Community effort to reduce weevil losses can be made effective in localities where beans and peas are grown on a commercial scale. It is doubtful if concerted action can be secured in towns or cities where there are many small gardens yielding but a few seeds, for these small quantities of seed are of too little value to move their owners to action. The University of California during 1918–1920 conducted a campaign of community effort, in San Mateo County, Calif., directed against the broad-bean weevil (p. 15) and found that by working through the county agent and fumigating the crops after they were placed in storage the infestation in the field was reduced from 43 per cent in 1918 to 21 per cent in 1919 and to 17.8 per cent in 1920.

Similar community campaigns are being conducted in other regions for the control of the common bean weevil and the southern cowpea weevil. The county agricultural agent has here a worth-while field for action along with his many others. To succeed, all farmers in a district should treat their seeds and dispose of all refuse and bean straw before the next bean crop approaches maturity.

TREATMENT DOES NOT PREVENT REINFESTATION

Treatment of legumes subject to infestation by weevils that can breed generation after generation in storage will not keep them free from weevils if they are stored so that adult weevils can get to them

and lay eggs on them. The application of remedial measures may kill all weevils in the seed at the time of treatment, but it should be remembered that no treatment has a lasting effect in preventing reinfestation from outside sources. Seeds once treated should be stored in rooms free from adult weevils, or placed in tight barrels or sacks made of closely woven material, and should be examined occasionally as a guard against subsequent infestation.

When large quantities of seeds are brought together under one roof, they usually represent the crops of many farmers whose local conditions may have varied to such an extent that one carload lot of seed may be free of infestation while the next may be slightly or heavily infested. Experimental work has proved that sacking seeds in one thickness of lightweight close-weave muslin will prevent un-

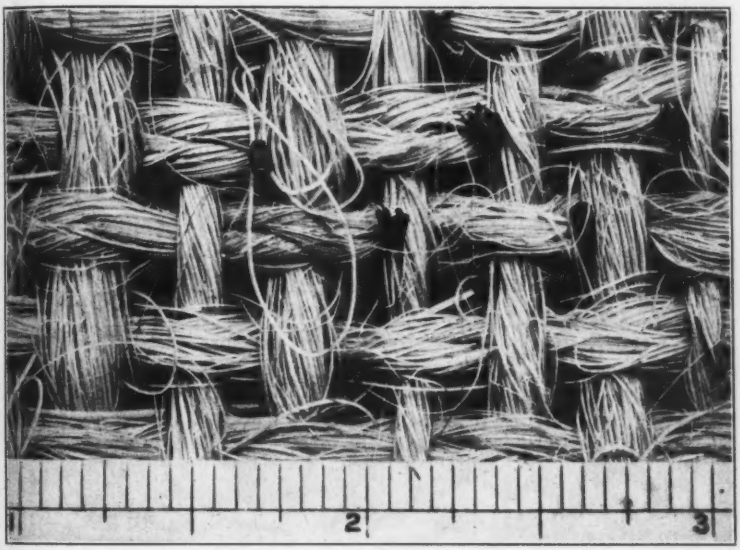

FIG. 28.—Section of jute sack having four strands to the inch. Such sacks are of no value in preventing spread of infestations from sack to sack in warehouses. The adult weevils can leave or enter such sacks at will

infested seed from becoming infested even though there are many weevils and weevilly seeds close by. It is not practical in large seed warehouses to use sacks of lightweight muslin, yet a study in 1917–18 of conditions in large warehouses containing many carload lots of seed indicates the value of closely woven sacks. Jute sacks with but four strands to the inch (such as shown in fig. 28) are no protection to the seeds within the sack and do not prevent weevils developing in the sacks from crawling out and migrating to and laying their eggs upon seeds in other sacks of similar weave. But seeds sacked in heavy cotton sacks of close weave with 24 strands to the inch are apparently perfectly protected from infestation from without. (Fig. 29.) Some such sacks contained badly damaged and heating seed but the infestation was held within them and prevented

from spreading to adjoining sacks by the tightness of the sacks. The common bean weevil and the southern cowpea weevil can eat holes in paper sacks and escape, but do not eat through cloth. There is

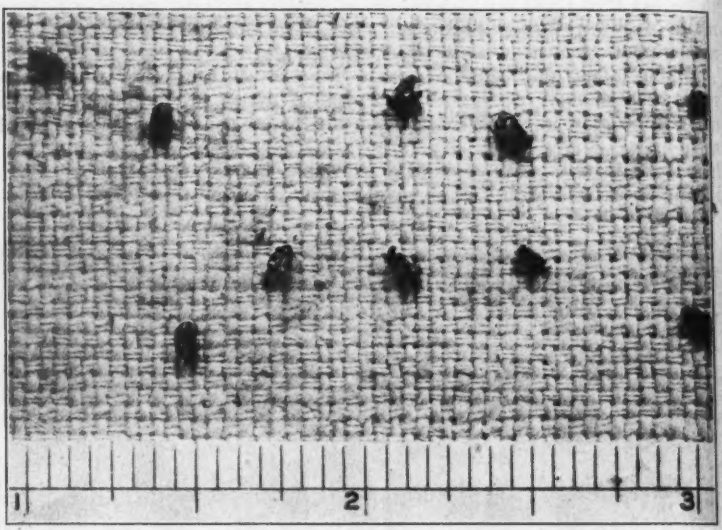

FIG. 29.—A heavy cotton close-woven sack with 24 strands to the inch. Sacks made of this material are on the market and have proved their effectiveness not only in preventing weevils from leaving the sacks but also in protecting uninfested seeds from infestation from without

a great deal in favor of a tight cloth sack, not only for protecting uninfested seeds from infestation from outside sources but also in preventing infestations from spreading.

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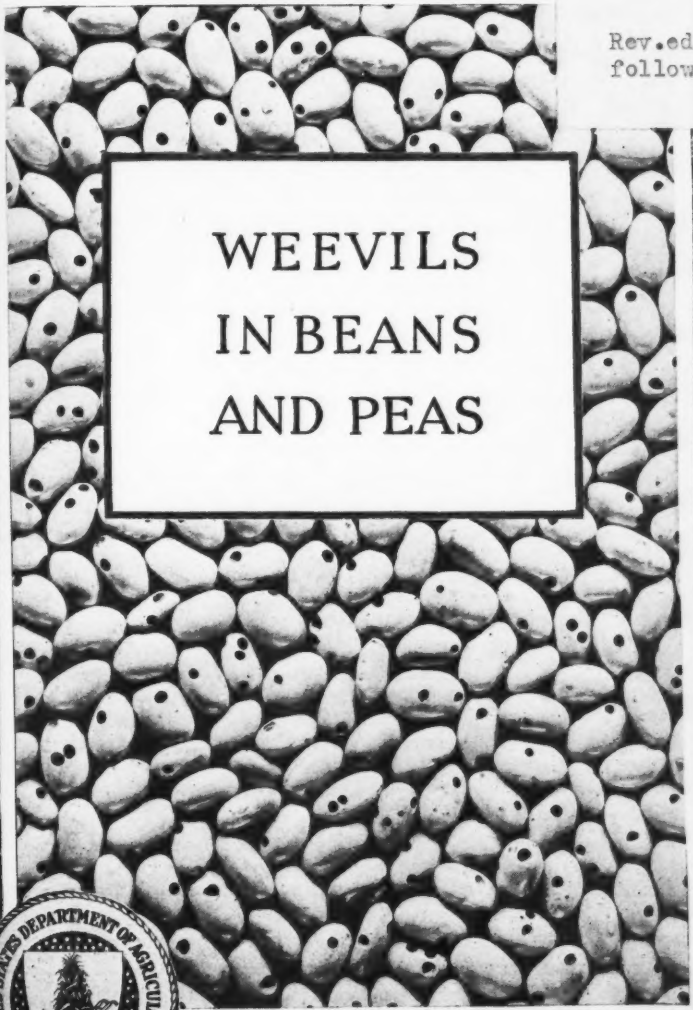

WEEVILS IN BEANS AND PEAS

XUM

BEANS, peas, and cowpeas are often damaged seriously in storage and in the field by weevils. Velvetbeans and soybeans are rarely infested in this country. Bean, pea, and cowpea weevils not only destroy an important part of the Nation's food in the form of leguminous crops but are responsible for a curtailment in the acreage planted to these crops. They never attack corn and wheat.

A large percentage of the initial infestations occurs in the field, where the parent weevil lays her eggs on or in the pods. The grubs, upon hatching, burrow into the seeds by gnawing a hole no larger than a pinprick. This entrance hole is usually not observed; hence the often expressed erroneous belief that the adult weevils that eat out from the seed, leaving behind a round hole about one-sixteenth of an inch in diameter, have "developed from the germ."

The most injurious bean and cowpea weevils in the United States can breed generation after generation in dried seeds in storage. During the hottest summer weather one generation requires about 1 month for development. Female weevils may lay as many as 50 to 58 eggs a day, though the average total number of eggs laid by an individual during her life is about 100. Infested seeds in bulk usually heat, thus producing temperature and moisture conditions most favorable for the rapid development and vigorous breeding of weevils.

Infestations in beans and peas can be quickly and effectively stamped out by fumigation with any of the fumigants commonly available, or by means of heat or cold storage. Weevils can be prevented from breeding in storage by mixing dust or air-slaked lime with the seeds. Concerted action by a community of growers has been known greatly to reduce weevil infestations and is recommended unreservedly for consideration in commercial bean-growing areas.

For the direct control of the pea weevil, apply dust mixtures containing 0.75 percent of rotenone to canning and garden peas—and, where practicable, to peas grown for seed—within a few days after the peas start to bloom.

In brief: Plant weevil-free seeds, harvest as soon as possible, treat to kill weevils, and store where seeds can be protected from reinfestation by weevils spreading from infested seeds.

Preventive and remedial measures are described fully in this bulletin.

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WEEVILS IN BEANS AND PEAS

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SERIOUS LOSSES CAUSED BY BEAN AND PEA WEEVILS

Bean and pea weevils are by no means new pests. They belong to a class of insects that cause farmers and merchants of this country an annual loss of many thousands of dollars.

The pea weevil is one of the major pests of garden and field peas, whether grown for canning, for seed, or for dry edible peas, throughout a large part of the United States where these crops can be grown. According to data compiled by workers of the Bureau of Entomology and Plant Quarantine, it is estimated that during recent years, particularly during the period 1934–37, the pea weevil has caused an annual loss of approximately $600,000 in the crops of peas grown for seed or for canning in the States of Idaho, Oregon, and Washington alone. These losses have consisted principally of (1) infested dry peas, which have to be discarded; (2) the cost of removing infested peas from seed peas or dry-pea products; (3) the abandonment or destruction of badly infested pea fields or portions thereof to avoid including weevily peas in the canned or processed product; (4) the expense of determining the locations of fields, or parts of fields that should be abandoned; and (5) the cost of material, labor, supervision, and machinery for applying insecticides.

[1] The original edition was prepared while the author was in charge of the Division of Stored Product Insect Investigations of the former Bureau of Entomology. In the reorganization of the work with the establishment of the Bureau of Entomology and Plant Quarantine, this Division was discontinued, and the author has since been associated with the Division of Insects Affecting Man and Animals. This revision was prepared in collaboration with D. J. Caffrey of the Division of Truck Crop and Garden Insect Investigations.

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The bean weevil has been one of the principal factors in discouraging the production of field beans in many districts of the South and Southwest and in California, except at the higher altitudes. This pest is considered one of the worst enemies of all types of garden beans grown in this territory. The southern cowpea weevil is commonly found associated with the bean weevil as a pest of cowpeas, beans, peas, and other seeds in the southern part of the territory infested by the bean weevil. The cowpea is now recognized as one of the most valuable cover crops for enriching the soil; and agriculturists claim that one of the important limitations to its more general use for this purpose and for fodder and human consumption is the susceptibility of cowpea seed to infestation by the southern cowpea weevil and the bean weevil. These two weevils are an important factor in maintaining the high cost of cowpea seed and in the consequent curtailment of the use of this plant as a soil builder, even in years of normal production. Because of the rapidity with which these weevils destroy cowpeas grown for human consumption, seedsmen and merchants have tended to view with suspicion all cowpeas grown in sections known to be badly infested by these insects, and this attitude has had a depressing effect on the production of cowpeas for food. Instances of losses sustained from the bean weevil and southern cowpea weevil are numerous. For example, it is reported that in 1926 these two species cost the growers of beans and cowpeas between $1,000,000 and $1,250,000 in San Joaquin, Stanislaus, and Merced Counties, Calif. Recorded losses to individual growers of these crops from weevil damage range from $75 to $8,000 a year.

FIGURE 1.—Navy beans showing the emergence holes of weevils. Each of these holes is made by a weevil as it matures in the seed and leaves by cutting out a piece of the skin. All except the five small beans at the bottom have been injured by the common bean weevil. The five small beans were grown in Central America, and have been infested by the Mexican bean weevil. About natural size.

Since the introduction from Europe of the broadbean weevil into California about 1909, the damage caused by this pest is estimated

to have caused a reduction of from 25 to 75 percent in the acreage formerly planted to Windsor beans, also known as broadbeans or horsebeans.

It is evident from the foregoing that the various species of weevils attacking beans and peas should be charged not only with the damage they cause leguminous foods actually produced, but also with the indirect losses to the country due to the reduction in the areas planted to beans, peas, and cowpeas.

LOSSES OFTEN DISCOVERED TOO LATE

Injury to edible legumes usually is observed first after the crop has been in storage for several months. Many believe that once the crop has been harvested it needs no further attention. Seeds put away at harvesttime are sometimes not examined again until the following planting season, when they are found "buggy" or "weevily" and badly damaged. The town or city gardener has proudly put away for winter consumption beans grown during the previous summer, only to find them worthless as food and full of holes and honeycombed by grubs when later he opens the jar or sack in which they have been stored. Wonder is often expressed that seeds apparently sound when put away for the winter, and kept always well covered, should be found later injured by weevils. Because small round holes (see title page and fig. 1) and weevils appear later in seeds seemingly perfect when harvested, a belief is current among many that bean and pea weevils develop spontaneously from the germ of the seed. That there is no foundation for such a belief is shown by the facts following.

HOW BEANS AND PEAS BECOME INFESTED

Bean and pea weevils, like many other insect pests, pass through several marked changes in form and habits before reaching maturity. The story of development is shown in figure 2. The weevil that is seen crawling about among the seeds is the parent insect. Many of these fly from the storage room or house to the fields where beans and peas (fig. 3) are growing. As the bean and pea pods develop, the mother weevil lays whitish eggs, either on the outside or within the pods. These eggs are so small that they are often not noticed for they appear as mere white specks upon the pods. From these eggs there hatch white grubs that burrow their way through the pod into the soft developing beans or peas. Because these grubs are so very tiny, the holes through which they enter the seeds are too small to be seen unless one searches for them with a microscope. Usually beans become infested first when they are nearly or quite full-grown. As the seeds expand and harden in the final ripening process the holes in the skin through which the grubs entered become less and less easy to find. The wound in the skin either becomes entirely healed over or remains similar in appearance to a small pinprick.

Since beans and peas mature much faster than the weevil grubs within them, it happens that the weevil grubs are comparatively small or little developed, in many instances, when the crop is har-

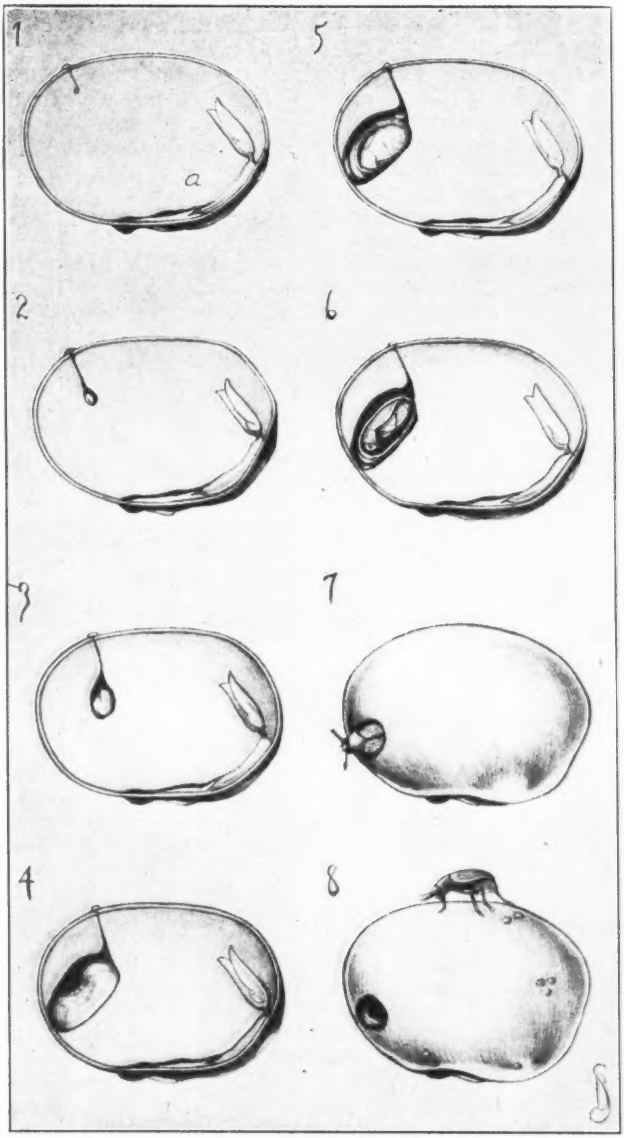

FIGURE 2.—Life cycle of the southern cowpea weevil: 1, Cross section of seed showing embryo or germ at *a*, and on upper left side an eggshell and the small burrow made by the newly hatched grub from the underside of egg into the seed; 2, 3, and 4, larva or grub in different periods of growth, the larva of 4 being full-grown; 5, pupa, or resting stage, which is intermediate between the larva and the adult; 6, side view of beetle within the pupal cocoon ready to gnaw the round hole in the seed coat so it can crawl out of the seed; 7, beetle has eaten a circular hole in the seed coat and is crawling out (note that this emergence hole is some way from the point of entry); 8, female beetle laying eggs on the seed.

FIGURE 3.—Field peas in bloom. Adult pea weevils begin laying their eggs on the young pods in the field. Photograph by Vinal.

FIGURE 4.—Wagon loads of field peas brought to mill to be threshed. Remember that the pea weevil, the broadbean weevil, and the lentil weevil are the only weevils mentioned in this bulletin that cannot breed in dried seeds in storage. For this reason any infestation by these weevils occurs only in the field while the crop is maturing; hence the weevil grubs are in the seeds at the time they are harvested, shelled, or threshed, and any treatment at that time, if done thoroughly, will prevent the development of holes in seeds resulting from the emergence of adult weevils.

vested (fig. 4) and placed in storage. Thus many seeds that appear outwardly in excellent condition in reality have weevil grubs hidden away in their interior, as shown in figure 2.

WHERE WEEVILS IN STORAGE COME FROM

At harvesttime the weevil grubs developing from eggs laid on or in the pods of beans, peas, or cowpeas in the field may have devoured very little of the seed contents, but if the seeds are stored in a warm place, or in a climate where the weather is sufficiently warm, they continue to feed and become well-grown. When well-grown, they have eaten out of the seed contents a cavity somewhat larger than themselves, extending outward to, but not puncturing, the skin of the infested seed (fig. 5). The grub then changes or transforms into the pupa (figs. 9, *c*, and 14, *c*) and later into the adult. This adult has a pair of sharp jaws which it uses like a pair of scissors to cut out a circular flap (fig. 6) in the seed skin, thus making the small round hole which is, to most gardeners, the first evidence that insects are in the seed. Through these openings the adults crawl out and by their presence in sealed jars and other containers cause much concern.

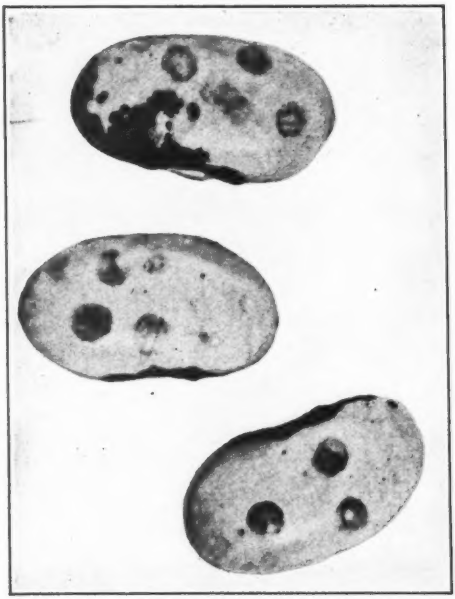

FIGURE 5.—Beans in which the bean-weevil grubs have become full grown and have eaten out from the interior of the bean to, but not puncturing, the skin. As they transform to adult, each insect darkens, and this dark color shows through the thin skin and makes the dark, sometimes bluish, translucent spots in beans. Such spots indicate that seeds are infested. It should be remembered that while the grubs are still growing they are white, and seeds do not indicate their presence by any such dark spots as shown above. Three times natural size.

THE TWO GROUPS OF WEEVILS

The principal kinds or species of weevils known to attack beans, peas, cowpeas, and similar crops may be divided, roughly, into two groups as follows:

Group 1, consisting of the pea weevil (*Bruchus pisorum* (L.)), the broadbean weevil (*B. rufimanus* Boh.), and the lentil weevil (*B. lentis* Boh.), attacks the seeds in the field only, at a time when the seeds are in a green growing condition. These species cannot reproduce on dry seeds and will die without leaving any progeny unless they can find growing host plants on which to lay their eggs. They have only one generation each year.

Group 2, consisting of the bean weevil (*Acanthoscelides obtectus* (Say)), the southern cowpea weevil (*Callosobruchus maculatus* (F.)), the cowpea weevil (*B. chinensis* (L.)), and the Mexican bean weevil (*Spermophagus pectoralis* Say), not only attack the seeds in the field but also continue to reproduce several successive generations each year in the dried seeds, usually in storage, when temperature conditions are suitable (fig. 7). Because each generation of these species of weevils injures the seed for planting and for food, steps should be taken to kill, at harvest time, such weevil grubs as may be in the seeds and thus prevent further losses. If this is not done the seeds become honeycombed by the feeding of successive generations of the grubs and may be reduced to a powder (fig. 8). Since the bean weevil, the southern cowpea weevil, the cowpea weevil, and the Mexican bean weevil breed in dried seeds, it is especially important not to store

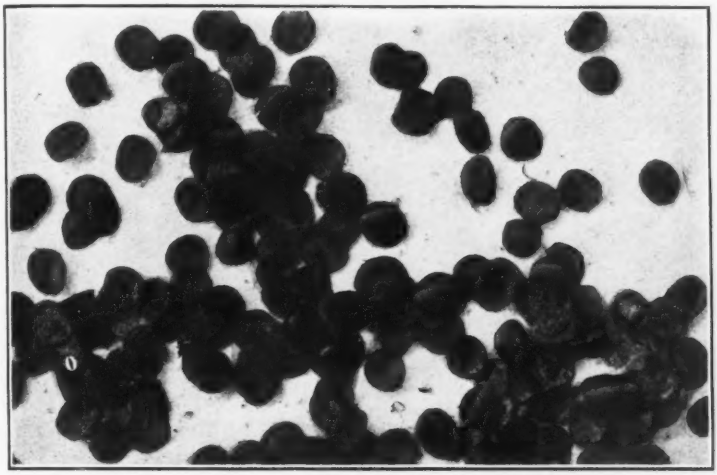

FIGURE 6.—In escaping from beans, peas, or cowpeas, or any host, weevils leave behind them the small round holes familiar to all. In making these holes they use their jaws to cut around the dark spots shown in figure 5 and then push away the circular flap of skin just as one opens a tin can of preserved fruit with a can opener. These circular bits of skin, shown above, about four times natural size, may be found among the seeds.

uninfested seed near seed that contain these weevils, for they will spread rapidly and soon infest all exposed seed in the vicinity.

GENERAL DESCRIPTIVE FACTS

The bean and pea weevils of the United States, considered in this bulletin, are all very small. None of them are more than one-eighth to one-fifth of an inch long. They are dull-colored, with markings of white or black. For the general shape, size, and arrangement of these markings, see figures 9, 12, 14, 15, 18, and 20. Their eggs are from one-fiftieth to one-twenty-fifth of an inch long, white or whitish, and appear as specks (figs. 16 and 17) when laid on beans and cowpeas in storage.

The larvae, or grubs, naturally are very small when first hatched and are white. After feeding, they become somewhat maggotlike

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in general appearance, being nearly cylindrical, fleshy, distinctly wrinkled, more or less curved in outline, and not more than one-fourth of an inch long and usually less.

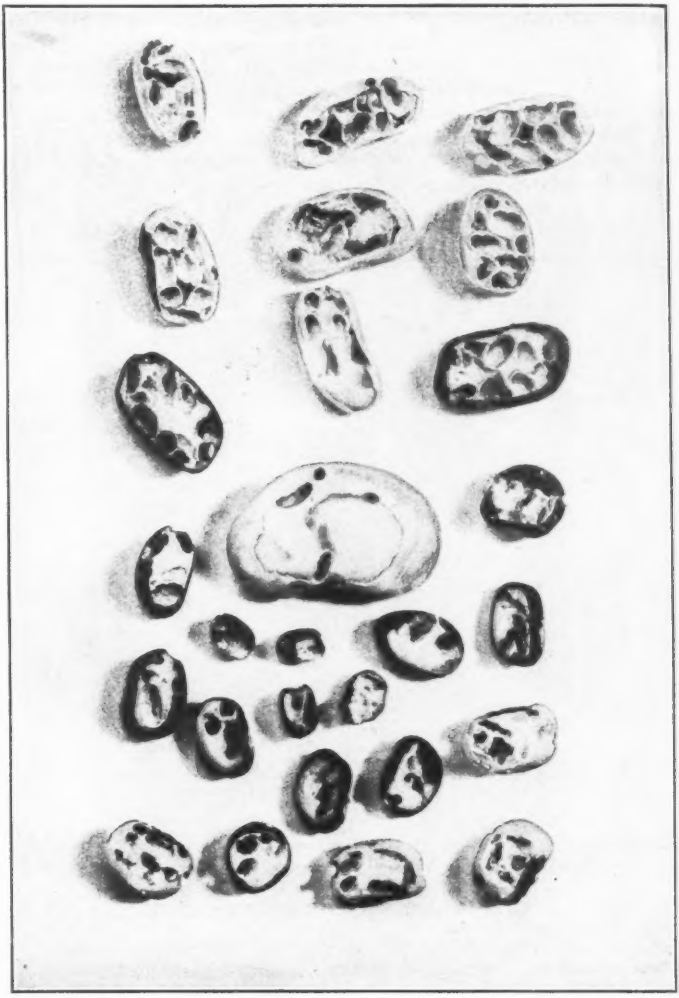

FIGURE 7.—Various types of beans and cowpeas cut lengthwise to show how severely they may be damaged by bean and cowpea weevil grubs. Such beans and cowpeas are not fit for human food. Slightly enlarged.

By the time the grub has become full-grown it has eaten out in the seed contents a cell in which to transform to the pupa or chrysalis. Before transforming, it secretes a substance which hardens into a white, filmy cell about itself, and this serves to protect the helpless

pupa while the changes making it an adult are taking place. For the general shape and appearance of the grub and pupa see figures 9, 14, 15, and 18. The pupal cells are shown in figure 22. For the general life cycle see figure 2.

FIGURE 8.—Leguminous crops may be reduced to a powder by the continued feeding of weevil grubs. In the bottom of sacks or boxes in which weevily beans or cowpeas are held for a long time one finds quantities of dead weevils and the powdered remains of the seeds such as are shown above. About natural size.

WEEVILS THAT ATTACK SEEDS ONLY IN THE FIELD

THE PEA WEEVIL

The pea weevil is one of the most important insect pests of the field or garden pea. It now occurs over almost the entire globe wherever peas are cultivated. Serious damage to garden peas in Pennsylvania, New Jersey, and southern New York was caused as early as 1748, and nearly all growers of garden peas are familiar with the exit holes that are made by the insects in dried seed (fig. 11).

Losses caused by the pea weevil are especially heavy in the case of garden and canning peas. Because close inspection is required to detect the occurrence of weevil grubs in green peas, even where moderately abundant, their presence only rarely comes to the attention of consumers. Such infested peas are considered unfit for human food, however, and are regarded as adulterated under provisions of the Federal Food and Drugs Act. In the case of seed peas the presence of the pea weevil seriously affects their germination, and large losses result because of the necessity of separating the weevily from the sound peas before they are fit for sale. When dried peas are offered for human consumption the presence of the pea weevil therein renders such products liable to seizure by health officials on account of contamination.

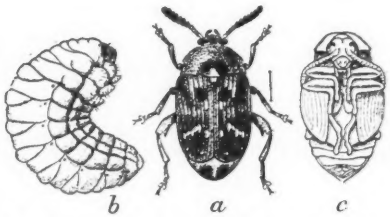

FIGURE 9.—Pea weevil; *a*, Beetle; *b*, larva or grub; *c*, pupa. The line to the right of the adult (*a*) represents the actual length of the beetle, and the sizes of the larva and pupa are in proportion. (Chittenden.)

The pea weevil is a small grayish or brownish-gray beetle about a fifth of an inch long. It is marked with black and white spots as shown in figure 9. The short line to the right of the adult in the illustration gives the actual length of the beetle. The adults appear on the vines when the peas come into bloom. They feed principally on the petals of the pea flowers and on the succulent tissues of the stems and pods, as shown in figure 10. While they eat holes in the petals and gnaw out long narrow slits in the stems, they do not appear to damage the plants materially, as the damaged flowers produce normal pods and the slits in the stems soon heal over and do not cause wilting.

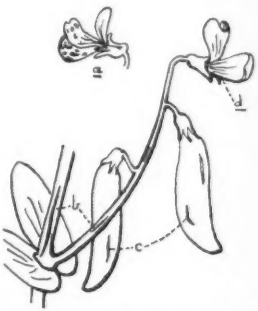

FIGURE 10.—Plant of garden pea showing, at *a*, holes in blossom where pea weevil beetles have fed; at *b*, slits in stem; and at *c*, cuts in pods made by the feeding beetles. The beetle finds its favorite shelter at *d*. (Skaife.)

The adults show a strong tendency to remain dormant during the season of the year when growing peas are not available for attack. Thus while certain beetles having access to pea plants lived only 4 or 5 weeks, others were found alive in dried seeds 14 months after the seeds were gathered. The female weevils lay their yellowish eggs singly upon the surface of the pods, to which they attach them with a peculiar viscid secretion. The young grub, upon hatching, gnaws through the pod and burrows into the seed, where it does practically all its feeding. While as many as six young grubs have been found in single seeds, it is seldom that more than one matures and emerges (fig. 11).

The length of time required for the eggs to hatch and for the grub or larva to mature to the adult varies with the climate. In the District of Columbia adults have appeared as early as July 21. Others have been reared as late as the middle of August. A very considerable

portion of the beetles mature and leave the seeds in the latter part of the summer in the latitude of Washington, D. C., but farther north and in higher altitudes the adults remain in the peas until the following spring, when they emerge in storage or are planted with the seed, or they emerge from the seed by harvesttime and seek hibernating quarters. Adults sometimes emerge in such numbers during the threshing of the peas in certain northern field infestations as seriously to annoy the workmen. It is largely in the adult stage that the weevil passes the winter, hibernating either in secluded spots in fields or buildings or in the pea seed itself. The pea weevil has only one generation a year and cannot reproduce in dried peas.

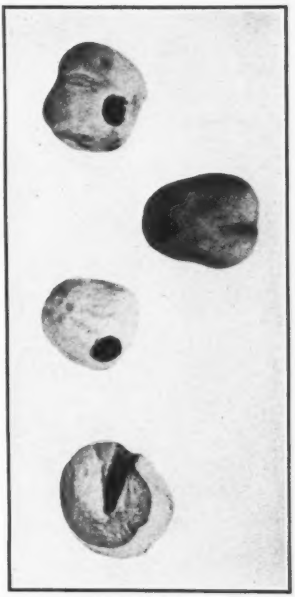

FIGURE 11.—Garden peas showing exit hole of the pea weevil. Note that only one weevil develops in a single pea. One seed has been sectioned to show cavity made by grub. Twice natural size.

THE BROADBEAN WEEVIL

The broadbean weevil closely resembles the common pea weevil, being about the same size, one-fifth of an inch long, and of similar appearance. It can, however, be readily distinguished by its much narrower thorax and fainter markings, as a comparison of figures 9 and 12 will show.

The broadbean weevil (fig. 12), sometimes called the European bean weevil, is common and destructive in Europe and northern Africa. While it feeds upon various sorts of beans and peas, it appears to prefer the broad or Windsor beans (fig. 21). Although it has been found from Canada to Texas in Windsor beans imported into various parts of this country, the first discovery of its definite establishment in the United States was made in 1909 at San Luis Obispo, Calif., where it was injuring the broad or Windsor bean (*Vicia faba*) grown for stock feed.

FIGURE 12.—Adult of the broadbean weevil. Enlarged six times. (Chittenden.)

Since then, and up to 1920, it has spread to include the coastal counties of California, from Sonoma to San Luis Obispo, besides San Benito, Santa Clara, Alameda, San Joaquin, Sacramento, Yolo, and Napa. Practically every broadbean entering a New York warehouse is more or less damaged by this pest. A single grub in its development consumes approximately 3 percent of the bean. Sometimes as many as six weevils develop in a single bean. Beside the actual amount of seed consumed, there must be considered the frass of the insect left behind in the seed, and this still further reduces the value of the crop. An infestation of over 15 percent bars any lot of beans from shipment under the Federal pure food law. It has been stated that of the entire broadbean crop of California for the years

1916, 1917, and 1918, 31.21, 18.01, and 43.08 percent, respectively, were above the allowed limit of weevil infestation, and therefore could not be shipped unless hand-picked. In 1916 the average percentage of infestation for the entire 1916 crop in the Halfmoon and Gilroy regions was above the 15-percent limit, while the same was true for the Sacramento and Halfmoon districts for the 1918 crop. After a campaign of seed fumigation in San Mateo County during 1918, 1919, and 1920 it was reported that the percentage of the broadbean crop infested above the tolerance limit was reduced from 43 percent in 1918 to 21 percent in 1919 and to 17.8 percent in 1920. Since beans uninfested, or infested less than 15 percent, were worth during these years from 5 to 6 cents per pounds, and others only 2¼ to 3 cents, it is easy to appreciate the dollars and cents value of concerted action among growers in applying cheap but effective remedial measures.

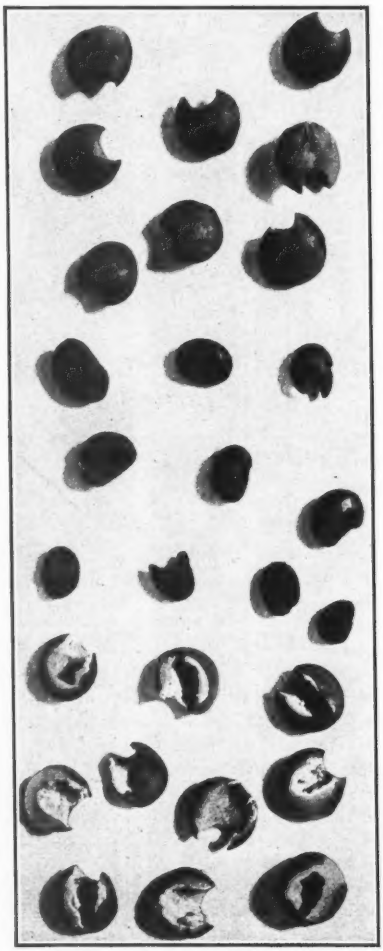

FIGURE 13.—Lentils of two varieties showing injury by the lentil weevil. While only one lentil weevil matures in a single seed, it is capable of practically destroying that seed, as indicated by the sectioned seeds at the bottom of the illustration. Somewhat enlarged.

The following biological facts are taken from a report of experiments conducted at Alhambra, Calif. The egg stage of the broadbean weevil lasts from 9 to 18 days, the larval stage from 10 to 15 weeks, the pupal stage from 7 to 16 days, and the beetle lives from 1 to 8 months. The eggs are laid on the green bean pods in the field from the middle of March to the middle of May; the larvae reach maturity from August to October, while the adults can be found from August to the following June. The broadbean weevil has but one generation each year and cannot start new generations in dried seed in storage; that is, such beetles as emerge from the seeds in storage have developed exclusively from eggs laid in the field upon the green pods and can do no further injury in warehouses.

THE LENTIL WEEVIL

The lentil weevil is not known to be established in this country at the present time, although it has been found repeatedly in imported lentils from Europe. It is an enemy of the lentil crop in middle and southern Europe, Egypt, and Syria. Since lentil growing is on the increase in this country, it is hoped to keep this pest from becoming established in North America.

The lentil weevil, only one of which matures in a single seed, resembles somewhat the pea weevil but is only about an eighth of an inch long. Like the pea and broadbean weevils, it has but one generation a year. The emergence holes and injury caused by this weevil are shown in figure 13.

WEEVILS THAT ATTACK SEEDS IN FIELD AND IN STORAGE

THE BEAN WEEVIL

The bean weevil is one of the most formidable enemies to the culture of beans in the United States as well as in many other countries. It occurs in nearly every State and in the Territory of Hawaii, and is generally distributed throughout Mexico, Central America, and South America. It has been found in beans imported from southern Europe, Persia, India, China, Algeria, South Africa, Madeira, the Azores, and the Canary Islands. Commerce has carried it to all the larger markets of the world. So severe is its attack in the warmer sections of this country that dried beans for seed and for food are grown mostly in the more northern States and California. In the South and Southwest and in California bean growing is made very difficult, if not rendered unprofitable, by the unmolested increase of the bean weevil.

The bean weevil is smaller than the pea weevil, being only about an eighth of an inch long. It is shaped and marked as illustrated in figure 14. The adult, or beetle, is so coated with fine hairs that it appears brownish gray or olive color. Unlike the pea weevil, the bean weevil not only can develop in growing beans in the field, but can also breed generation after generation in dried beans in storage.

The adults may live as long as 9 weeks, though usually 2 weeks represents their more normal length of life during the active season. Of course, adults may remain alive in a dormant condition for several months in dried seeds during cold weather.

The female weevils may fly from storage quarters early in the summer and from then on may be found upon the bean plants. While the weevils lay their eggs in largest numbers through cracks in the pod that develop during the drying out of the pod, the female has been observed to gnaw holes in green pods and to lay her eggs through such holes. Eggs are never glued to the outside of the pod as is the habit of several other species of bean and pea weevil. In storage the eggs are laid singly and loosely (i. e., unattached) among the seeds. As many as 59 eggs may be laid by a single female in 1 day, and a total of 209 eggs during her life. As many as 67 eggs have been found laid through a crack in a bean pod.

As many as 28 weevil grubs have been found in a single bean. All varieties of garden beans are attacked, even lima beans being severely damaged during 1920 and 1921 in New England.

Experiments have demonstrated that the eggs of the bean weevil require from 5 days in the hottest weather to 20 days at a cooler temperature to hatch, and that the larvae or grubs become full grown in from 11 to 42 days and the pupae in from 5 to 18 days, according

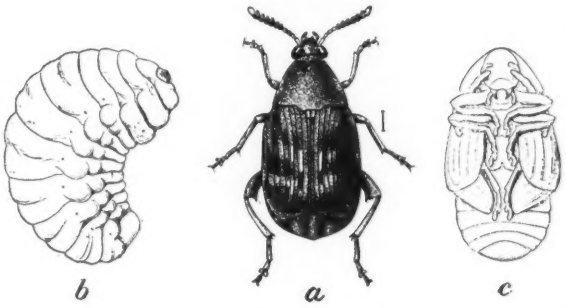

FIGURE 14.—Bean weevil: *a*, Beetle; *b*, larva or grub; *c*, pupa. The short line to right of the beetle (*a*) represents its real length. (Chittenden.)

to the temperature. It requires 21 to 80 days at least, according to the season and locality, for a generation of the bean weevil to develop. In the District of Columbia there may be as many as six generations a year. The warmer the climate the greater the number of generations and the consequent damage done by the grubs.

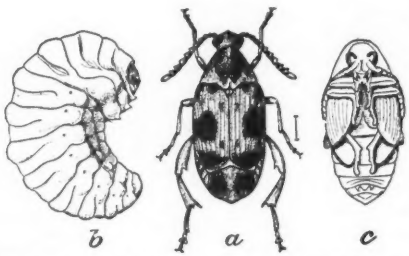

FIGURE 15.—Southern cowpea weevil: *a*, Beetle; *b*, larva or grub; *c*, pupa. Six times natural size. (Chittenden.)

In a climate similar to that of the District of Columbia and adjacent parts of Maryland and Virginia, adults of the first generation started in the field begin to emerge as early as October. If the fall is early and the seeds are stored in a cold place no adults may emerge before the following spring. If seeds are stored in a warm place, adults may emerge at any time during the winter. After emergence in storage the adult females lay eggs either on the beans or on the sides of the receptacles in which the seeds are stored

THE SOUTHERN COWPEA WEEVIL

The southern cowpea weevil is a major pest of cowpeas in the United States. The female is about one-eighth of an inch long and is distinguished by four black spots upon the wing covers as shown in figure 15. In 1885 this species was found swarming on blackeye cowpeas from Texas exhibited at the Atlanta Cotton Exposition. Since then it has spread throughout the Southern States, California, and as far north as Iowa, and is probably present wherever cowpeas are grown.

The cowpea is its favorite host food, although peas and beans are attacked (figs. 16, 17, and 19). While female weevils may lay eggs upon the pods and seeds in the field, and hardly a crop of cowpeas matures in the South without an abundant infestation, this weevil breeds most prolifically in dry seeds in storage. It does not lay its eggs loosely among the seeds as does the common bean weevil, but glues them to the seed, as shown in figure 17, and the presence of these white specklike eggs in any consignment is always an indication of infestation.

The adult weevil lives, on an average, about 15 days. While the average number of eggs laid per female in certain experiments was 82, as many as 196 eggs were laid by one female. Usually the largest numbers of eggs are laid during the first few days of adult life. One female weevil laid 22, 15, 15, 14, 6, 13, 2, 11, 6, 0, 0, and 2 eggs respectively on the first 12 days after leaving the seed in which she developed. Death soon follows the completion of egg laying. Eggs hatch in from 4 to 6 days during warm summer weather. During the cold winter weather in Texas eggs require from 25 to 37 days for development. The percentage of eggs that hatch in winter is very small, while that in summer is very high. The length of the larval stage ranges from 9 days to more than 8 months. During warm summer weather from 17 to 22 days is usually required. Larvae emerging from eggs laid late in the fall require long periods for development and pass the winter as dormant grubs within seeds in cold warehouses. Taking the egg, larval, and pupal stages into consideration, it is safe to say that development requires from 30 to 48 days during warm weather.

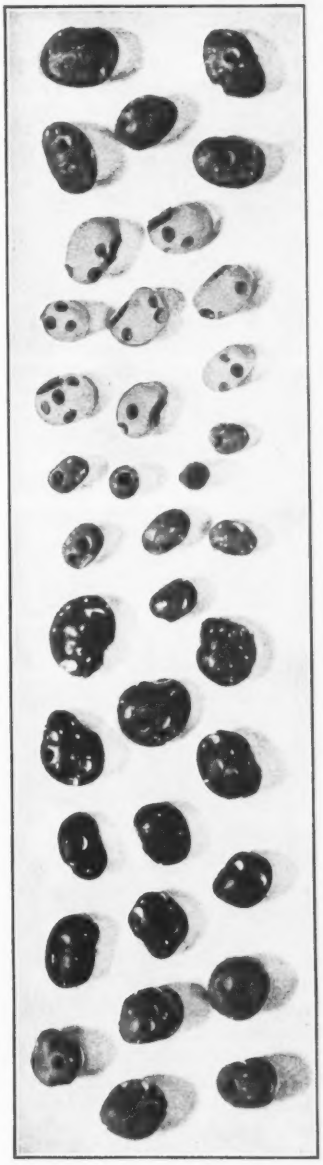

FIGURE 16.—Different varieties of cowpeas showing infestation by southern cowpea weevil. Seed about natural size: the white specks on the seeds are the eggs of the weevil.

THE COWPEA WEEVIL

The cowpea weevil (fig. 18) is a foreign species first described from

China. It has been reported from every continent and is likely to be found in any commercial center. From 1898 to 1911 it was known to be well distributed and often abundant throughout the Gulf Coast States and even as far north as Washington, D. C. It is now a pest of minor importance in the United States, where it has not been observed for some years. Although it prefers cowpeas, it may attack the common pea, pigeon pea, lentil, chickpea, mung bean, and the common white bean.

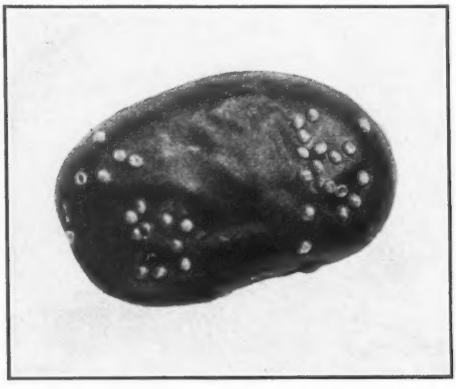

FIGURE 17.—A cowpea seed showing eggs of the southern cowpea weevil. The eggs of bean and pea weevils vary in shape but are always small, ranging in length from one-fiftieth to one twenty-fifth of an inch. They are white or whitish, and may be laid anywhere upon the outside of the seed, as indicated here, or in cavities in the seed made by a previous generation of grubs, or on sides of containers such as burlap sacks, barrels, etc. The eggs can be distinctly seen on seeds, as tiny white specks. Five times natural size.

The adult weevil is about an eighth of an inch long and may be distinguished from other weevils discussed in this bulletin by elevated ivorylike spots near the middle of the body, shown in figure 18. Its biology is similar to that of the southern cowpea weevil. During very hot weather a generation may mature in 21 days (egg, 4 days; larva, 13 days; pupal stage, 4 days). This period is lengthened by cooler weather and may approximate 3 or 4 months during winter weather. This insect glues its whitish eggs to the surface of the seeds, as does the southern cowpea weevil, and is capable of breeding indefinitely in dried seeds in storage.

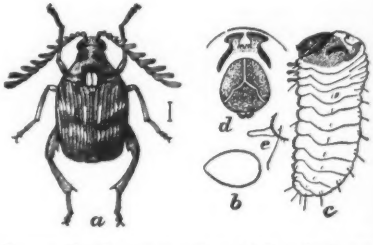

FIGURE 18.—Cowpea weevil: *a*, Adult male; *b*, egg; *c*, postembryonic larva; *d*, front view of head of same, *e*, thoracic leg of same; *a*, six times natural size; *b–e*, more enlarged. (Chittenden.)

The adults live on an average 5 or 6 days during the hottest weather and as many as 40 days during the winter months in the Gulf Coast States. Activity is likely to cease entirely at a mean temperature of 50° F., or below, when the insects will seem dead to all outward appearances and only resume activity when the weather becomes warm. While the immature stages may be passed in as few as 16 or 17 days, 21 days is closer to the normal time required during hot summer weather. The longest period for larval development yet recorded is 88 days, from December to March, in Texas, when the temperature ranged from 22° to 86°. There may be from 8 to 10 generations a year in the Gulf Coast States.

THE MEXICAN BEAN WEEVIL

The Mexican bean weevil is an inhabitant of South and Central America and is occasionally found at our Pacific and Atlantic ports, infesting beans imported from these countries. It attacks beans and cowpeas. It breeds continuously in dried seeds and is capable of being as injurious as the common bean weevil, as indicated by the five small beans affected by this pest, shown at the bottom of figure 1. For the size, shape, and marking of this insect, see figure 20. The adult lays her eggs upon the seeds to which they are stuck by a cement similar to that used by the southern cowpea weevil (fig. 17). While occasionally intercepted at ports of entry for many years past, this species does not appear to have become established in the United States.

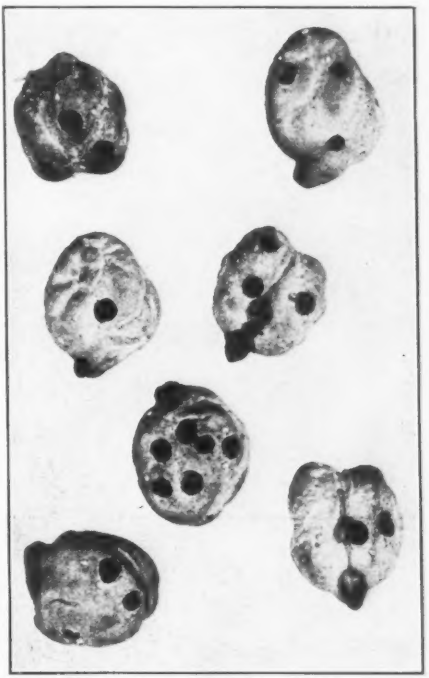

FIGURE 19.—Chick peas affected by the southern cowpea weevil. Compare these with the two sectioned chick-peas at the bottom of figure 22. Twice natural size.

WHY WEEVILS LIMIT ACREAGE PLANTED TO CERTAIN LEGUMINOUS FOOD CROPS

It has been pointed out already that infestation nearly always takes place in the field while the crop is maturing. With garden or Canada peas, lentils, and broad or Windsor beans infested with the pea weevil, the lentil weevil, and the broad bean weevil, respectively, this is always the case, for these weevils never breed in dried seeds. Other species that breed in dried seeds, as well as in the field, may spread in storage to uninfested seeds and badly infest them. It is generally known that the colder the winters the shorter the growing season and the fewer the bean and pea weevils that survive the cold of winter and are ready to fly to the fields to start the infestation of the growing crop by laying eggs on the pods. The farther south one goes the more mild the winters become, the longer the growing season, and the greater the number of weevils that can live through the winter.

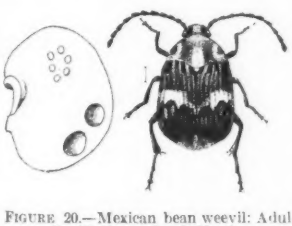

FIGURE 20.—Mexican bean weevil: Adult weevil with line to left indicating actual length. Infested bean to left showing two emergence holes and six eggs. (Chittenden.)

As far south as the District of Columbia and the adjacent tidewater country of adjoining States, therefore, overwintering weevils attack the beans and peas in large numbers and succeed in years favorable for them in laying so many eggs upon the pods that each developing bean becomes affected and often may support as many as 20 to 28 weevil grubs. Because of the long, warm falls and the length of time the plants are allowed to remain in the field after the crop has ripened, either standing in the ground or pulled and stacked, these grubs are given every opportunity to develop into adults or at least to become very well grown in an unusually large number of cases, and therefore they cause greater damage than do weevils in beanfields farther north. Thus beans grown in latitudes south of New York City, except in higher altitudes, as in the mountainous regions of the Alleghenies, become more infested than those grown north of that latitude. As

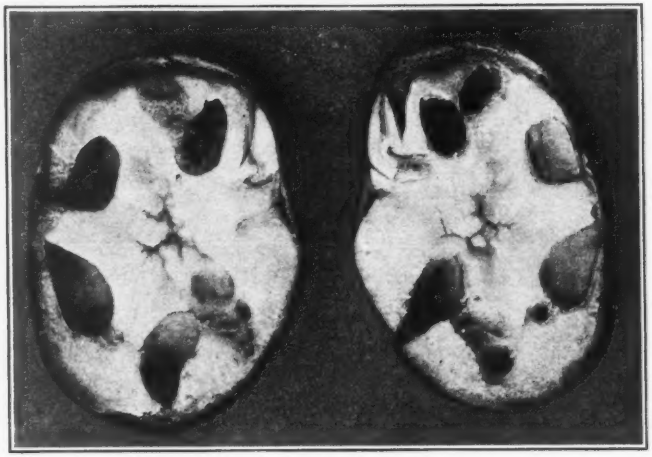

FIGURE 21.—A broad, horse, or Windsor bean, cut open to show the damage caused by grubs of the broad-bean weevil. Only one generation of this weevil occurs each year. As each cavity represents the feeding of one grub, this bean is badly affected. Considerably enlarged.

weevils in beans are not killed so easily as are many other insects and as their presence in numbers in beans is objectionable whether beans are grown for food or for planting, even when the grubs have been killed (fig. 22), the growing of beans on a commercial scale for dried seeds has largely been given up in our more southern latitudes. This explains the question often asked why beans and peas grown in portions of California, Michigan, New York, Washington, Oregon, or Idaho, or even in Canada, find their way into our southern markets, which one would expect to be supplied by southern-grown beans and peas. Practically all the dried beans grown for seed and for food are grown in these Northern States, where the bean weevils are not able, because of climatic checks, to cause so much damage. Of course weevils do not affect the growing beans to be eaten green, as string beans or green shelled beans, for such beans either are not, at the time of gathering, infested; or if infested, the grubs are too small to interfere with the food value of the beans.

GERMINATION AFFECTED BY WEEVIL ATTACK

The germination of beans, peas, and cowpeas is likely to be seriously affected by the development of weevil larvae. If the embryo is destroyed by the larva or if too much of the bean substance is eaten, the seeds cannot grow.

Beans as badly infested as those shown in figures 1, 7, and 23 are worthless for planting. As the young bean or pea plant depends upon the food stored in the seed to give it its start, the destruction of any portion of the seed by weevils lessens by so much the vigor of the plant. In one experiment on record, only 50 percent of infested beans germinated, and of these 30 percent were so badly injured that they could not develop into normal plants. The smaller the seed, the greater proportional damage a single weevil grub can cause. One grub ruins a small cowpea seed (fig. 16) or a lentil (fig. 13), whereas it would not so seriously affect a large seed like the lima bean. The germination of broadbeans infested with 1, 2, 3, and 4 or 5 broadbean weevils was found to be reduced from a normal of 95.7 to 82.7, 72.7, 71.1, and 69.6, respectively. Of 50 garden peas infested by the pea weevil examined, 33 were found with the embryo wholly or partially destroyed, and in another case only 69 out of 275 infested peas had undamaged embryos or germs.

FIGURE 22.—Beans (six upper seeds) and chick-peas (two lower seeds). The skin of the beans has been removed to reveal the cavities eaten out by the bean weevil grubs. The grubs have been killed by fumigation and have turned black. Note the white paperlike cell or cocoon about each of the grubs. The chick-peas have been cut open to show how the larvae of the southern cowpea weevil can burrow to the very center of the seed. Slightly enlarged.

HEATING DUE TO INFESTATION

It is a well-known fact that beans and peas, as well as grains, will heat if insects become sufficiently abundant in them. In bean warehouses where the seeds are stacked, as shown in figures 25 and 26, centers of weevil infestation can be detected by walking past the tiers of sacks and allowing the hand to pass over the sacks. Experience soon makes it easy to detect heating sacks. Heating seeds also produce an odor quickly detected by experienced persons when they enter a warehouse after it has been closed for a few hours.

The ability of bean and pea weevils to produce heating of the seeds is of great importance. Were it not for this ability, owners could rest assured that if warehouses were open to outdoor temperatures below 50° F. no injury from weevils would take place. Certain weevils develop most quickly when the temperature ranges between 75° and 95°, and egg laying is greatly stimulated by these higher temperatures. At temperatures ranging from 75° to 95° the development of the southern cowpea weevil has been known to be completed in 18 days; hence heating caused by weevil infestation, with the accompanying increase in moisture content of the seeds, may result in an outbreak of weevils at a season of the year when least expected. The temperature of a 240-pound sack of chick-peas infested by the southern cowpea weevil may be raised by infestation to at least 103°. It is not uncommon in some warehouses to find a considerable number of sacks the temperature of which has been raised to over 80° or 90°. In one instance, when the daily maximum temperatures ranged between 50° and 58°, sacks within 2 feet of an open window registered

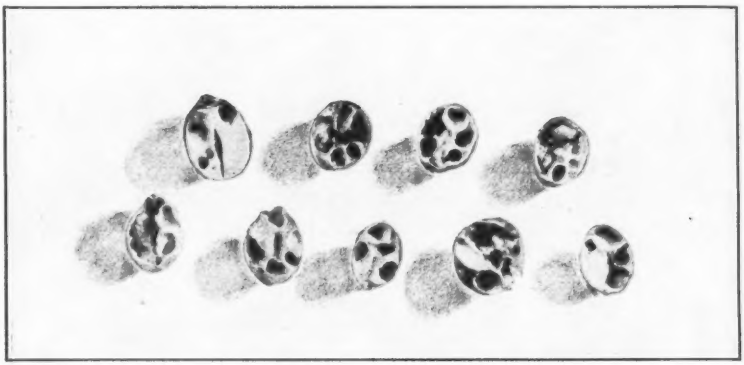

FIGURE 23.—Navy beans cut crosswise to prove how the bean weevil can ruin seeds for eating or planting. About natural size.

102°. The temperature in the spaces between heating sacks was raised in this warehouse from 58° to a minimum of 70° and a maximum of 78°. At 58° adult weevils were too cold to migrate, but at 70° to 78° they were very active and were spreading from heating sacks to surrounding sacks and laying eggs upon previously uninfested seeds.

This effect of heating, due to infestation, upon spread of injury from sack to sack, to say nothing of increase in infestation within the individual sacks during cold weather, should be understood by those holding beans and peas in storage; otherwise, serious losses may occur. Fumigation with hydrocyanic-acid gas (p. 30) kills the insects, reduces the temperature to normal, and stops the spread. Fumigation with any efficient fumigant will probably have the same result.

GENERAL METHODS USED FOR THE CONTROL OF WEEVILS IN BEANS AND PEAS

In applying methods for the control of the seven kinds or species of weevils discussed in this bulletin it must be remembered, as stated previously, that these species of weevils fall into two distinct groups;

that is, the first group, which consists of weevils that attack seeds only in the field, and the second group, which consists of weevils that attack seeds both in the field and in storage. Many of the methods of control, however, are nearly the same for both groups. These control methods may be summarized as follows:

(1) Plant weevil-free seed. Large numbers of weevils are able to escape from infested seeds and infest the growing crop.

(2) Harvest and thresh or shell all seeds from weevil-infested fields as soon as they are ripe, before weevil emergence occurs, and in order that the seeds may be more easily and cheaply treated to keep the weevil grubs from further feeding and maturing. Storing in the pod does not confine the weevils. The grubs continue their development and transform to adults in the unshelled as well as in the shelled seeds. The adult weevils can then gnaw their way out of the dried pods.

(3) Immediately after they are harvested, place the seeds in tight bags having at least 24 strands to the linear inch (fig. 28) in order to prevent the escape of such weevils as may emerge from the seeds within the bag and to prevent the species of weevils that attack dry seeds from gaining entrance to the bags.

(4) Fumigate infested seeds as soon as possible after harvest to prevent further development of the contained weevils.

(5) Eliminate all shattered seeds and other crops remnants that may remain on the field surface after harvest, by clean plowing, burning, pasturing with livestock, or any other available method that under local conditions will accomplish the utilization or destruction of these common sources of reinfestation.

(6) Feed to livestock, or plow under deeply and cleanly, or burn, or otherwise utilize or destroy, the straw or viner refuse from fields of peas, beans, or cowpeas before the weevils contained in any seeds have a chance to emerge and infest the new crop. In such refuse there are usually seeds that were missed during the threshing, shelling, or vining process.

(7) Clean up possible hibernating or overwintering quarters of weevils, adjacent to or near cultivated fields, such as brush-filled fence rows, abandoned orchards, and dilapidated fences and buildings.

(8) Beans, cowpeas, or peas stored on the farm, in warehouses, or in other storage places should be examined at frequent intervals and fumigated when necessary. In weevil-infested warehouses special precautions should be taken to keep the floors and cleaning machinery free from susceptible seeds, and general sanitary measures should be instituted to clean up all possible sources of weevil infestation.

(9) In combating the pea weevil, the general control methods discussed in the preceding paragraphs can be supplemented, in the instance of valuable crops, or in home gardens, by insecticide applications as described later in this bulletin.

(10) It should be emphasized that any remedy that lessens the number of weevils present in the field reduces the number of weevils that must be fought in storage, and similarly the use of proper control methods in storage reduces the number of weevils that must be combated in the field.

CONTROL OF THE PEA WEEVIL

IN PEAS GROWN FOR CANNING AND FOR THE GREEN PEA MARKET

Supervision Important

Supervision is an important factor in the success of a large-scale control program. When extensive operations along the lines suggested in these recommendations are to be undertaken it is important that the program be under the direction of a competently trained person who knows the scientific facts regarding the weevil and its habits. It should be the duty of this person to determine when and where to apply control measures on each field and to check the results of this control whenever possible.

Use a Dust Mixture Containing Rotenone

Experiments and extensive tests on a commercial scale conducted in Oregon, Washington, and Idaho in 1936 and 1937 have demonstrated that the pea weevil can be controlled in canning and garden peas by the application of dust mixtures containing rotenone derived from derris or cube. The mixture should contain not less than 0.75 percent of rotenone, with talc or some similar inert carrier used as a diluent. The recommendations that follow may require distinct modification in some cases.

Rate of Application

From 20 to 25 pounds of the dust mixture per acre should give satisfactory results if applied with an efficient dusting machine. Where the infestation is particularly heavy, as in some border strip plantings, the use of an additional 5 pounds of the dust mixture per acre should give greater assurance of successful control of the pea weevil.

Time and Number of Applications

The first application of the dust mixture should be made a few days after the peas start to bloom and before any pods have formed on the vines; otherwise the weevils may lay eggs on the young pods. Additional weevil populations may fly into some of the fields; in that event one to two additional applications may be necessary. The time of these later applications depends upon when the weevil population increases in the field. In most instances a 6- to 10-day interval between applications has been satisfactory.

Area to Be Dusted

In general the dust mixture should be applied to any fields or parts of fields where weevils can be found by sweeping with an insect-collecting net. Since the pea weevil in migrating from hibernation quarters to the peafields has a tendency to infest the field edges first, it is possible to secure adequate control in each field by applying the dust mixture to a marginal strip of varying width. If the field contains 10 acres or less, it is advisable to apply the dust mixture to the entire field in order to obtain satisfactory results. For large-scale control campaigns, each field should be examined, and the parts of each field found infested should be treated with the dust mixture.

DUSTING EQUIPMENT

The control effected by applications of the dust mixture is increased by the use of dusters with hoods constructed over the dust nozzles.

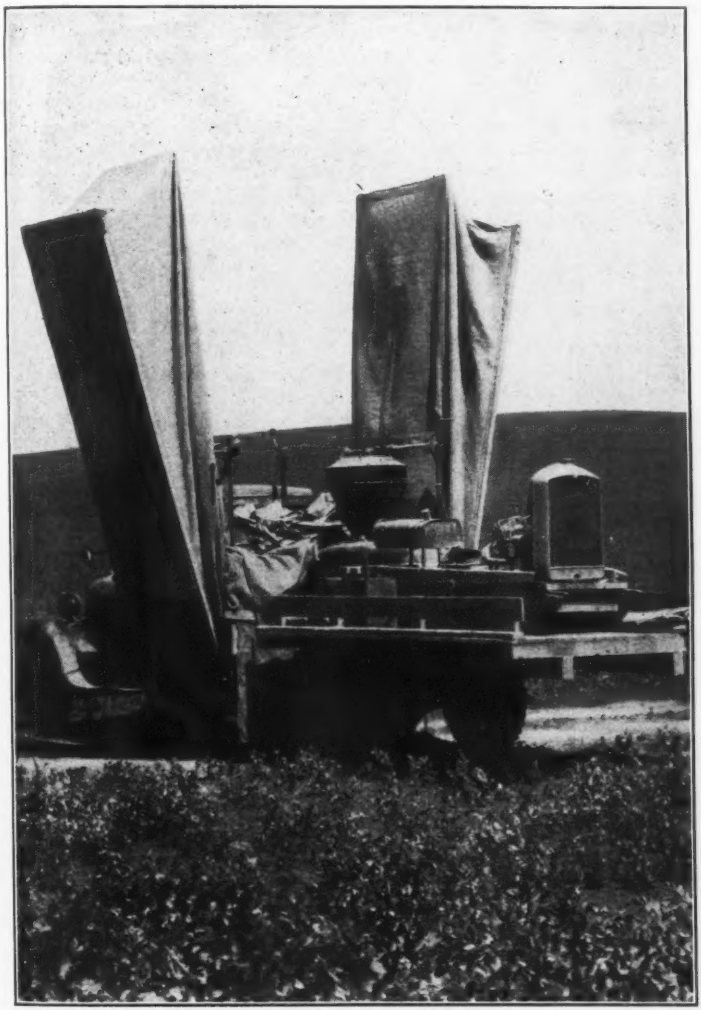

FIGURE 24.—Duster used in pea weevil control in the Pacific Northwest. The hoods on this duster have been raised to show their flexibility and construction. When in operation, they extend horizontally and at right angles to the truck. The nozzles are located under the hoods and adjacent to the truck body and blow the dust the full length of the hoods.

The type of duster used most successfully during the 1937 season had hoods 3 to 4 feet high and 4 to 5 feet wide projecting from 15 to 20 feet on each side of a truck or trailer (fig. 24). The length of the hoods,

however, may be varied to meet individual needs. It should be possible to raise or lower the hoods to adjust their height to the height of the peas, and they should be weighted at the bottom with iron rods or some heavy material to prevent whipping by the wind. The hoods should be so constructed that they may be raised to a vertical position or otherwise folded out of the way, and they should be easy to dismantle. When the dust mixture is being applied to border strips only, it should be possible to shut off the dust mixture on one side of the machine. All the dusting equipment should be of the sturdiest construction in order to reduce break-downs, since a difference of even 1 day in time of application of the insecticide may make considerable difference in the degree of control obtained. The use of hooded dusters makes it possible to apply dust mixtures under windy conditions.

Figure 24 shows a duster used in pea-weevil control work during the 1937 crop season. The hoods, attached over the outlet nozzles, have been raised to a vertical position.

APPLY DUST MIXTURES TO GARDEN PEAS TO CONTROL THE PEA WEEVIL

Like those in large-scale operations, the peas in small gardens should be treated with the dust mixture before any pods appear on the vines, and this treatment should be repeated when a careful examination of the vines shows that any weevils are present. The dust mixture should be applied at the rate of approximately 25 pounds per acre or one-fourth of a pound to 100 linear feet of row.

Plant Border Trap Crops

The use of border trap plantings is advocated because in most instances they have served to attract the majority of the weevils to where they can be killed by dusting with the mixture containing rotenone before the main field comes into blossom. The plantings should be one drill wide (10 feet) and should be sown so that the peas in the strips will blossom from a week to 10 days before blooms appear in the main plantings. It is necessary that the weevils in these borders be destroyed by applying the insecticide before the main crop blossoms. The peas in the borders may become heavily infested later in the season, so the vines should be plowed under or otherwise destroyed as soon as they have gone out of bloom.

Sanitary and Preventive Measures

Sanitary measures to prevent the development and escape of the pea weevil from infested peas are of equal value with the application of dust mixtures containing rotenone as a means of reducing weevil populations from year to year. The most important of these sanitary measures are the following:

PLANT WEEVIL-FREE SEED

Never plant seed containing living weevils. Large numbers of weevils are able to escape from such seeds and infest the growing crop.

DO NOT GROW SEED PEAS IN CANNING AND GREEN-PEA DISTRICTS

Peas allowed to ripen for seed in canning-pea areas are the primary source of pea weevil infestations. Salvaging overripe canning peas as seed only breeds more weevils to infest succeeding crops. The

development of the pea weevil can proceed without interruption in dry peas, and since the harvest loss in these peas is often extremely heavy, large numbers of weevils are able to complete their development. The production of seed peas also leads to the presence of many volunteer peas, in which additional pea weevils may breed and develop.

TAKE CARE OF VINER REFUSE

At the viner there is also a loss of peas in which pea weevils can complete their development. The best practice for weevil destruction and maintenance of soil fertility is to return to the land and immediately plow under all viner refuse. This material may also be stacked as ensilage for livestock. Few weevils escape from stacked viner refuse, since it decomposes rapidly. On the other hand, the insect is able to develop readily in refuse allowed to dry for hay.

PLOW UNDER FIELD REFUSE

The peas left on the field after the green pea crop is harvested can serve as a source of continued infestation. The most effective way now known to handle this refuse is to plow deeply immediately after harvest. Peas grown as a soil-conservation crop should be thoroughly plowed under shortly after they blossom; otherwise they constitute a distinct source of weevil infestation for all the peas in the area about them.

DESTROY THE VINES IN HOME GARDENS

Peas allowed to ripen in home gardens are a source of weevil infestation. Garden plantings should be periodically dusted with a dust mixture containing rotenone, and as soon as the peas get beyond the edible stage the vines should be destroyed.

CLEAN UP POSSIBLE HIBERNATING QUARTERS

The most severe damage in infested localities and on individual farms usually occurs where the peas are grown near good hibernating cover. Many places favorable for hibernation, such as brush-filled fence rows, can be cleaned up, and others, such as isolated trees, abandoned orchards, and dilapidated fences and farm buildings, can be readily removed. The value of such preventive measures varies with the number of favorable hibernating places near the peafields. Clean-up measures will be more effective in fields situated some distance from extensive timbered or brushy areas than in fields immediately adjacent to such areas.

IN PEAS GROWN FOR SEED

Plant Weevil-Free Seed

Much weevil-infested seed is planted with the thought that the insects will not be able to emerge from the seeds. Such is not the case, however, for experimental work has shown that large numbers of such weevils are able to escape.

Harvest Seed Peas Before Weevil Emergence Takes Place

Observations have shown that seed peas ripen and are ready for harvesting some time before the pea weevil is ready to emerge. All peas, therefore, can and should be harvested before emergence takes place. Usually it is profitable to harvest the peas as soon as they are ripe, in order to eliminate loss due to the shattering of overripe peas. Moreover, the fewer shattered off in the field, the fewer weevily peas left to increase infestation the following year.

Prevent Harvest Loss

The pea weevil problem in the Northwest starts with the peas lost during the harvesting process, for if all the peas were harvested before weevil emergence started and no weevil-infested seeds were lost on the ground or left unharvested, no weevils would survive to attack succeeding crops.

Harvest loss cannot be eliminated completely, but field counts indicate that the loss varies with the care used in harvesting the peas. Few peas are lost by an efficiently operated combine, but if the same machine is in the hands of a careless operator it can produce quite the opposite results.

Plowing under the shattered peas to a depth of 8 inches immediately after harvest has thus far proved the most effective method for destroying the weevils in peas lost during the harvesting process. Pasturing the fields, especially with sheep, results in the consumption of many weevil-infested peas. Such a practice is very beneficial if the pasturing is done before weevil emergence has started.

Apply a Dust Mixture

The application of dust mixtures having a rotenone content of 0.75 percent has also given beneficial results when applied to peas grown for seed. The same procedure as outlined for cannery peas should be followed in treating peas grown for seed.

Treat Seed

As soon as the peas are ripe they should be harvested into tight bags. This procedure reduces harvest loss, prevents the escape of weevils from the peas before they are harvested, and makes it impossible for the weevils to escape from the bags after harvest. Bags of peas containing living weevils should be fumigated, by methods described later in this bulletin, or otherwise treated to prevent the escape of weevils during the cleaning or milling process.

Austrian winter field peas should be fumigated immediately after harvest in order to kill any pea weevil larvae that may be present before these develop sufficiently to affect the germination of the seed.

CONTROL OF THE BROADBEAN WEEVIL

The general methods of control recommended for the pea weevil are also of value against the broadbean weevil, since the latter species does not attack the dry seed and has only one generation each year. As insecticides containing rotenone have not been tested against the broadbean weevil, no information is available regarding the possible

effectiveness of this method. In the control of the broadbean weevil particular attention should be given to the following points:

(1) Plant only weevil-free seed or seed that has been fumigated by methods described later or otherwise treated to kill all contained weevils.

(2) Infested seed that has not been fumigated or otherwise treated to kill the weevils should be kept in tight receptacles until the second year, by which time the infesting weevils will be dead.

(3) Infested seed that has not been treated to kill the weevils and cannot be kept in tight receptacles should be fed or otherwise disposed of before the planting season.

(4) Badly infested seed should be ground up in feed mills as soon as it is harvested.

(5) Planting of broadbeans in localities known to be infested by the weevil should be delayed until as late as possible, preferably after March 1 under California conditions. In the dryer and hotter localities where delayed planting is not possible, it is especially important to plant only weevil-free seed.

CONTROL OF THE LENTIL WEEVIL

Although no opportunity has been afforded to perform experiments on the control of the lentil weevil, it is believed that the control recommendations suggested for the pea weevil should be effective against the lentil weevil, since the habits of these two species are similar.

CONTROL OF THE BEAN WEEVIL AND THE SOUTHERN COWPEA WEEVIL

There are two distinct problems in the control of the bean weevil and the southern cowpea weevil, since these two species of weevils attack the crop not only in the field but also in storage.

The problem of control in the field can be solved by eliminating, prior to planting time or at least early in the growing season, all small or large lots of dried beans, cowpeas, and bean or cowpea straw on the farms and in the warehouses that serve as breeding places during the summer or crop-growing season. Danger from these sources may be eliminated by proper fumigation of the seeds by methods discussed later in this bulletin or by feeding the material to livestock or otherwise disposing of it. The only practical method of eliminating straw containing infested beans or cowpeas is to use it for feed or plow it under deeply and cleanly or burn it. The cleaning up of sources of infestation must be done thoroughly and efficiently by every person in a bean-growing community if satisfactory results are to be obtained. If a few sources of infestation are neglected, these may supply a sufficient number of weevils to infest an entire bean-growing district.

The control of the bean weevil and the southern cowpea weevil in the warehouse or other storage quarters depends on frequent and thorough examination of all beans or cowpeas stored therein, followed by efficient fumigation when necessary. The floors and cleaning machinery of weevil-infested warehouses should be kept free from beans or cowpeas, and general sanitary measures should be instituted to clean up all possible sources of weevil infestation.

CONTROL OF THE COWPEA WEEVIL AND THE MEXICAN BEAN WEEVIL

The general control methods suggested for the bean weevil and southern cowpea weevil should be followed in combating the cowpea weevil and the Mexican bean weevil.

FUMIGATION

All species of weevils mentioned in this bulletin may be killed in storage by fumigation with several materials, including carbon disulphide, carbon tetrachloride, an ethylene oxide-carbon dioxide mixture, hydrocyanic acid gas, and chloropicrin.

CARBON DISULPHIDE

Fumigation with carbon disulphide (CS_2) is one of the simplest remedies for weevils. Carbon disulphide is purchased as a liquid in iron drums or tin cans and weighs about 10½ pounds per gallon at ordinary temperatures. Upon exposure to air, the liquid evaporates or volatilizes, forming a foul-smelling gas that is about twice as heavy as air. Because the gas is heavier than air and evaporates more quickly if a larger surface of the liquid is exposed to the air, the liquid should be poured out into shallow pie tins or similar shallow dishes and placed upon the top of the seeds to be fumigated. Seeds will not be injured or poisoned if the liquid is sprinkled or poured directly upon them. In estimating the quantity of carbon disulphide needed, the total cubic space in the container in which the fumigation is done should always be considered—not just the amount of space occupied by the seeds.

If used according to directions, carbon disulphide will not injure the germination of thoroughly dry seeds or affect their value for food. The disagreeable odor passes away after seeds fumigated have been aired.

While carbon disulphide has become a standard fumigant and has been used for years without trouble by many individuals and firms, the fact must be emphasized that carbon disulphide is a highly inflammable liquid that will give off, at a temperature as low as −22° F., vapors that will explode if present in the air in from 1 to 50 parts in 100, if they come into contact with fire, sparks, or even hot metal.

The vapors can be ignited by any kind of flame, such as a lighted lantern, sparks from electric switches, or lighted smoking materials. Hot steam pipes, a heavy blow such as may be struck by a hammer, or even heating grain where the temperature rises as high as 212° F., may cause the vapor-and-air mixture to explode. The vapors are heavier than air and may flow along the floor a considerable distance to a source of ignition and flash back to cause an explosion.

Because of the fire hazard involved in the use of carbon disulphide, most insurance companies prohibit its use in buildings covered by their policies, except in certain cases where its use is permitted under conditions imposed by the companies.

From a fire and explosion standpoint, carbon disulphide is much more dangerous than gasoline.

Seeds to be fumigated should be placed in an air-tight container. This may be a tin pail, wash boiler, barrel lined with heavy paper, galvanized-iron garbage can, or other receptacle, or a specially constructed fumigation box or room, according to the quantity of seed to be fumigated. One of the simplest satisfactory containers for fumigation on a small scale is a water-tight barrel. The tighter the receptacle the better the results. Satisfactory results cannot be secured if fumigation is attempted in a container or room full of cracks.

Carbon disulphide should be used at the rate of from 4 to 20 pounds to each 1,000 cubic feet of space to be fumigated, the quantity to be used varying with the tightness of the container and the temperature. The liquid quickly vaporizes, and as the gas is heavier than air, it sinks to the bottom of the container, filling all the air spaces. Fumigation should continue from 24 to 48 hours, although most of the actual killing is done during the first 6 to 8 hours of exposure. It is always better to use too much rather than too little carbon disulphide.

Beans, cowpeas, and peas can be stored and fumigated conveniently in watertight barrels. These should be filled to within a few inches of the top with seeds. In fumigating, pour one-half cup or more of carbon disulphide on the seeds and then cover the top of the barrel with a double thickness of heavy wrapping paper tied tight around the top, or several sacks weighted down with boards. A wooden cover is also useful in keeping in the fumes.

To give the best results, fumigation with carbon disulphide should be carried on at or above a temperature of 75° F. It is not effective at temperatures below 60°. After fumigation the seeds should be examined occasionally and given a second or third fumigation in case living weevils are found.

Carbon disulphide costs from 6 to 25 cents a pound. It is cheapest when purchased in 55-gallon drums (550 pounds.) The cost is greatest when the liquid is bought in 1-pound cans, when the price may range from 25 to 40 cents per pound.

To these prices must be added transportation costs. Farmers throughout the country can purchase carbon disulphide at local drug stores, but prices under such conditions often are exhorbitant. County agents, boards of trade, or other public-spirited local organizations can purchase carbon disulphide and furnish it at cost to farmers in the vicinity. This has been done in certain southern towns with the result that farmers have secured carbon disulphide of excellent quality at lowest price.

CARBON TETRACHLORIDE

Carbon tetrachloride (CCl_4) is a fumigant that has been used as a substitute for carbon disulphide in fumigation work, since it has the advantage over carbon disulphide of being noninflammable. When pure, carbon tetrachloride is a thin, transparent, colorless liquid, with a pungent, aromatic odor. Except for being noninflammable, it is similar to carbon disulphide in all essential features, from the standpoint of application. It costs from about 5.8 cents per pound in large quantities to 10 cents per pound in small quantities. It is not likely to take the place of carbon disulphide because of its inferior killing qualities. Its great advantage is its noninflammability.

If carbon disulphide or carbon tetrachloride cannot be secured from local firms the names of firms supplying these chemicals may be obtained from the Bureau of Entomology and Plant Quarantine, United States Department of Agriculture.

ETHYLENE OXIDE-CARBON DIOXIDE MIXTURE

The ethylene oxide-carbon dioxide mixture is composed of one part of ethylene oxide and nine parts of carbon dioxide by weight. It is a noninflammable, nonexplosive gas and is not highly toxic to man. For these reasons this fumigant may often be used where insurance regulations or other restrictions prevent the use of other fumigants. The gas is sold in cylinders under pressure and is adapted chiefly for use in fumigating chambers. Moreover, it has the advantage of not leaving any appreciable odor in the fumigated product.

The ethylene oxide-carbon dioxide mixture should be used at the rate of 20 pounds per 1,000 cubic feet under average conditions, with suitable changes in this dosage according to the airtightness of the fumigating chamber. The period of fumigation should be the same as for carbon disulphide, and the room should be at a temperature not lower than 60° F.

The cost of this fumigant ranges from approximately 14½ to 16 cents a pound delivered.

Caution.—The ethylene oxide-carbon dioxide mixture should not be used to fumigate peas, beans, or other seeds intended for planting purposes, since this gas ordinarily injures the germination of such seed.

CHLOROPICRIN

Chloropicrin, one of the tear gases used in the World War, is now utilized to some extent in fumigating peas infested by the pea weevil. It possesses the advantage of being noninflammable and of costing less than some of the other fumigants, and it has given effective results when used according to directions.

Although this gas is a deadly poison, it has a disagreeable and irritating effect upon the eyes and the respiratory passages that prevents people from entering buildings or other structures where there are dangerous concentrations of chloropicrin. Moreover, the fumigated seeds must be thoroughly ventilated or air-washed before they can be handled, because traces of chloropicrin gas may be retained in the fumigated product for several days. When this gas is used in fumigating, 1 pint (or 1.7 pounds) of chloropicrin should be used for each 1,000 cubic feet of space. The treatment should continue for at least 36 hours, and it is most effective at or above a temperature of 75° F. It is not effective at temperatures below 60°.

To apply this fumigant sprinkle it on pieces of burlap sacking or pour it into shallow evaporating pans. A gas mask is essential if large quantities of chloropicrin are to be used.

Chloropicrin costs approximately $1.35 per pound, in 100-pound cylinders, exclusive of the cost of transportation.

HYDROCYANIC ACID GAS

Fumigation with hydrocyanic acid gas is recommended when large quantities of beans, peas, cowpeas, or chick-peas are found infested with weevils. The seeds must be in sacks and so stacked that the gas

can reach several sides or portions of the sacks. Chick-peas stored in 240-pound sacks, and stacked as shown in figures 25 and 26 were almost perfectly protected by fumigation. It has been found in the fumigation of warehouses, sometimes as large as 150 by 150 by 20 feet, and containing as many as thirty thousand 240-pound sacks of chick-peas, that hydrocyanic acid gas can be depended upon to eliminate infestations almost completely. Fumigation with this gas for the control of bean and pea weevils has proved so satisfactory that its use is now an established practice with certain firms. For seed so stored the dosage should be increased from the normal dosage of 1 pound of sodium cyanide for each 1,000 cubic feet of space to be fumigated to 2½ pounds per 1,000 cubic feet. Since it is extremely poisonous, hydrocyanic acid gas should be used only by responsible persons who are thoroughly informed on the subject of fumigation. As the gas is

FIGURE 25.—Carload lots of 240-pound sacks of chick-peas as stacked in a badly infested warehouse. Samples taken throughout the length of the sack proved that the hydrocyanic acid gas had penetrated to the very center and that the infestations were all killed.

lighter than air and readily escapes, does not injure the seeds for planting or for food, injures no warehouse equipment, and is non-inflammable when mixed with air in the proportions used in fumigation, it lends itself to use in almost any warehouse section if the fumigation is properly timed and supervised. More detailed discussion of the use of hydrocyanic acid gas as a fumigant is given in Farmers' Bulletin 1483 and Circular 369.

HEAT

Heat as a means of killing weevils in legumes is growing in favor. Small quantities of seed grown on the farm or in the town garden can be treated by placing them in an oven after they have been spread rather thinly in shallow pans and heating them to from 120° to 145° F. for several hours. An old remedy is to dip seeds into boiling water for 1 minute. Holding seeds in boiling water for more than 1 minute will injure their value for planting purposes, and immersion for even

1 minute has been known to affect germination. On removal they should be spread out immediately and dried rapidly.

Weevil development in large quantities of beans, peas, and cowpeas can be stopped by a process known as kilndrying. This process consists in heating the seeds to a temperature of 120° to 145° F., or higher, while they are being passed through a machine called a drier. This treatment not only removes a portion of the moisture in the seeds but also kills all insects in them. The loss of moisture may be an item of importance if sales are made by the pound, yet investigators claim that seeds containing 20 percent of moisture or less are not easily infested by weevils, hence excessive drying with the heat not only kills the weevils but renders seeds less susceptible to reinfestation.

FIGURE 26.—Interior view of a warehouse containing 30,000 240-pound sacks of chick-peas having a retail value of $864,000 at the time of treatment. Infestations breaking out under such abnormal storage conditions were controlled by fumigation with hydrocyanic acid gas.

The embryos of the bean weevil are killed when exposed to a temperature of 125.6° F. for 10 minutes; the newly hatched larvae die in 7 minutes at 131°; full-grown larvae in beans die in 20 minutes at 131°; and pupae die in beans when exposed for 25 minutes at 131°. Adults are killed by a 4-minute exposure at 131°. These data cannot be relied upon when large masses of seed are to be treated. It was found that 9 hours were required for the center of 2 quarts of beans inclosed in a tight paper bag to reach the surrounding temperature of 131°. Cowpeas infested with the southern cowpea weevil were not absolutely freed from insect infestation when exposed to 140° for 5 minutes, though all the weevils were killed when the seeds were exposed to this temperature for 10 minutes in an oven. These results in killing the southern cowpea weevil were secured under conditions more favorable than those likely to occur in commercial bean estab-

lishments, hence it is recommended that seeds be exposed in commercial treatment to 146° for 20 to 30 minutes. Temperatures above 150° seemed to weaken the resulting plants, but germination took place even after the seeds had been subjected to 190° for 10 minutes. Commercial coffee roasters are used by certain bean brokers for the destruction of weevils by heat. Seeds have been treated by the carload in such roasters and were guaranteed to remain free from injury by bean weevils at least during transit in carload lots. A list of firms that manufacture apparatus for heating seeds will be furnished upon application. As in kilndrying, the seeds should be spread out in order that all may be affected quickly and uniformly by the heat. When they are thus spread out, an exposure to 131° for 1 hour should be sufficient.

Heat is not recommended for the control of the broadbean weevil in broad or Windsor beans. Exposure to temperatures ranging from 120° to 140° for 5 to 40 minutes did not kill this apparently more hardy insect, and the higher temperatures had an injurious effect upon germination.

COLD AND COLD STORAGE

Weevils will not feed and cause damage at low temperatures. It is not known at what temperature development ceases, but no development takes place at or below 50° F. Cowpeas can be kept free from weevils if held in storage at a temperature of 32° to 34°. It is claimed that exposure for a season at this temperature does not affect the germinating power of the seed. Investigations conducted in this Bureau indicate that no stage of the common bean weevil can withstand 56 days of cold storage at 31° to 32°, although they may survive more than 66 days at 36°. The larvae, it appears, succumb to cold-storage temperatures more readily than do pupae or adults. The storage room should be kept as dry as possible, and the seeds should be handled in sacks as in warehouses. Cowpeas held for a season at 32° to 34° were found to lose their germinating power no sooner on removal to normal temperatures than cowpeas not thus exposed to cold. Seeds removed from cold storage to warm temperatures are likely to sweat, and if care is not taken to eliminate this surface moisture by drying or proper ventilation, moldiness may result. There is some doubt as to the real need of incurring the expense of cold storage, as seeds can be protected more cheaply by fumigation under storage conditions thought by the majority of seed owners to be better for the seeds.

LIME OR DUST AS A PROTECTION TO SEED

In the Southern States, where weevils cause such great injury to stored seeds, certain farmers have resorted to mixing their seed cowpeas with dry road dust or air-slaked lime. Tests prove that the storage of cowpeas with air-slaked lime at the rate of 1 part by weight of lime to 6 to 8 parts of peas is a great help in protecting seeds. The dust or lime does not necessarily kill the weevil grubs developing in the seeds if these are already in the seeds at harvest-time, but it prevents adult weevils either from emerging, or, if they succeed in emerging, from laying their eggs on the seeds for successive generations. The dust or lime, in other words, prevents continued breed-

ing in storage. Either substance would probably be a nuisance if mixed with cowpeas intended for food if the seeds contained many emergence holes, as the lime or dust would work into these holes and be difficult to remove. If seeds are known to be free from weevils and are stored in tight barrels, bins, or other similar containers, a top layer of air-slaked lime about one-half to 1 inch thick, if maintained, will prevent weevils from gaining access from without and starting an infestation.

COMMUNITY EFFORT TOWARD CONTROL

Anyone can protect beans and peas from further weevil injury after they are once dried and in storage. If loss occurs in storage, owners have only themselves to blame, for weevils can be effectively controlled at a cost very slight as compared with the value of the seeds protected and the increased value of the seeds after thorough treatment.

But no one person can prevent his beans and peas from becoming infested while they are developing in the garden or field unless he and his neighbors are willing to get together and pledge to treat their seeds in storage and to destroy other breeding places, such as bean-straw piles. Many adult weevils fly to fields from storage bins about the time the seeds are beginning to mature. A negligent neighbor may be the cause of much neighborhood infestation by the flying of his weevils to developing crops or into warehouses.

Community effort to reduce weevil losses can be made effective in localities where beans and peas are grown on a commercial scale. It is doubtful whether concerted action can be secured in towns or cities, where there are many small gardens yielding but a few seeds, for these small quantities of seed are of too little value to move their owners to action. The University of California during 1918–20 conducted a campaign of community effort, in San Mateo County, Calif., directed against the broadbean weevil and found that by working through the county agent and fumigating the crops after they were placed in storage the infestation in the field was reduced from 43 percent in 1918 to 21 percent in 1919 and to 17.8 percent in 1920.

Similar community campaigns are being conducted in other regions for the control of the bean weevil and the southern cowpea weevil. The county agricultural agent has here a worth-while field for action along with his many others. To succeed, all farmers in a district should treat their seeds and dispose of all refuse and bean straw before the next bean crop approaches maturity.

REINFESTATION NOT PREVENTED BY TREATMENT

Treatment of legumes subject to infestation by weevils that can breed generation after generation in storage will not keep them free from weevils if they are stored so that adult weevils can get to them and lay eggs on them. The application of remedial measures may kill all weevils in the seed at the time of treatment, but it should be remembered that no treatment has a lasting effect in preventing reinfestation from outside sources. Seeds once treated should be stored in rooms free from adult weevils or placed in tight barrels or sacks made of closely woven material and should be examined occasionally as a guard against subsequent infestation.

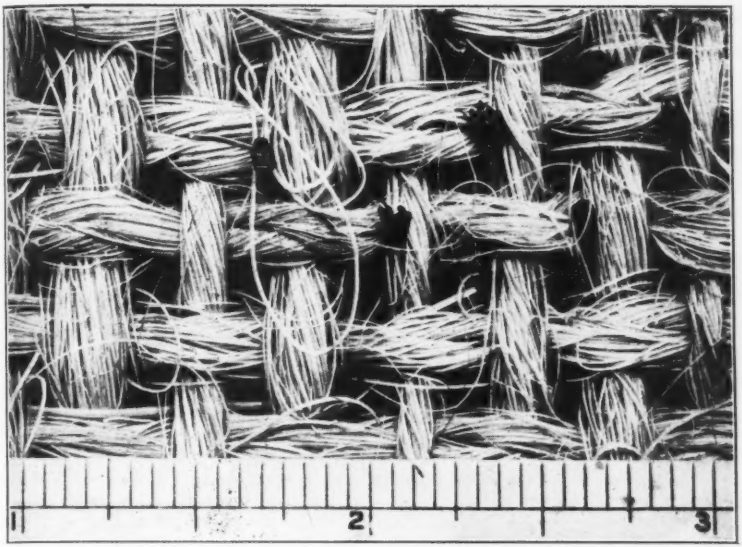

FIGURE 27.—Section of jute sack having about four strands to the inch. Such sacks are of no value in preventing the spread of infestations from sack to sack in warehouses. The adult weevils can leave or enter such sacks at will.

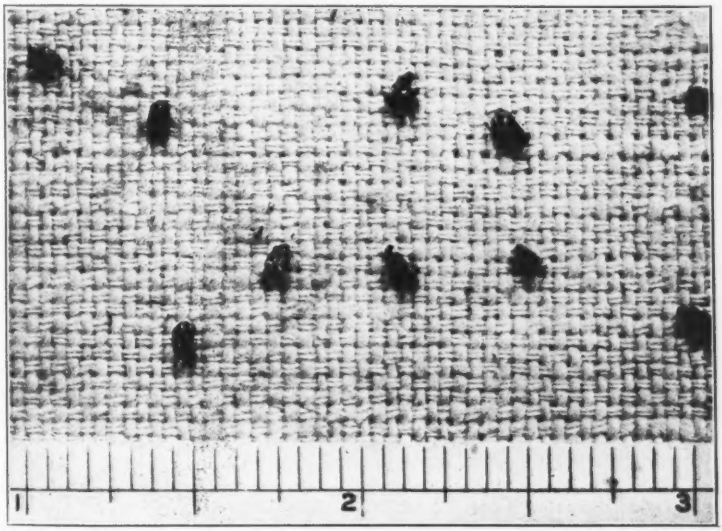

FIGURE 28.—A heavy cotton close-woven sack with about 21 strands to the inch. Sacks made of this material are on the market and have proved their effectiveness not only in preventing weevils from leaving the sacks but also in protecting uninfested seeds from infestation from without.

When large quantities of seeds are brought together under one roof, they usually represent the crops of many farmers whose local conditions may have varied to such an extent that one carload lot of seed may be free of infestation while the next may be slightly or heavily infested. Experimental work has proved that sacking seeds in one thickness of lightweight close-weave muslin will prevent uninfested seed from becoming infested even though there are many weevils and weevily seeds close by. It is not practical in large seed warehouses to use sacks of lightweight muslin; yet a study in 1917–18 of conditions in large warehouses containing many carload lots of seed indicates the value of closely woven sacks. Jute sacks with but four strands to the inch (fig. 27) are no protection to the seeds within the sack and do not prevent weevils developing in the sacks from crawling out and migrating to and laying their eggs upon seeds in other sacks of similar weave. But seeds sacked in heavy cotton sacks of close weave with 24 strands to the inch are apparently perfectly protected from infestation from without (fig. 28). Some such sacks contained badly damaged and heating seed, but the infestation was held within them and prevented from spreading to adjoining sacks by the tightness of the sacks. The bean weevil and the southern cowpea weevil can eat holes in paper sacks and escape, but do not eat through cloth. There is a great deal in favor of a tight cloth sack, not only for protecting uninfested seeds from infestation from outside sources but also in preventing infestations from spreading.

WHERE TO OBTAIN INSECTICIDES

Information regarding the purchase of the insecticide materials mentioned in this bulletin may usually be obtained through local dealers in agricultural supplies, seedsmen, general stores, drug stores, and department stores, or it may be secured from the county agricultural agent, State agricultural experiment station, State agricultural college, State department of agriculture, or the Bureau of Entomology and Plant Quarantine, United States Department of Agriculture.

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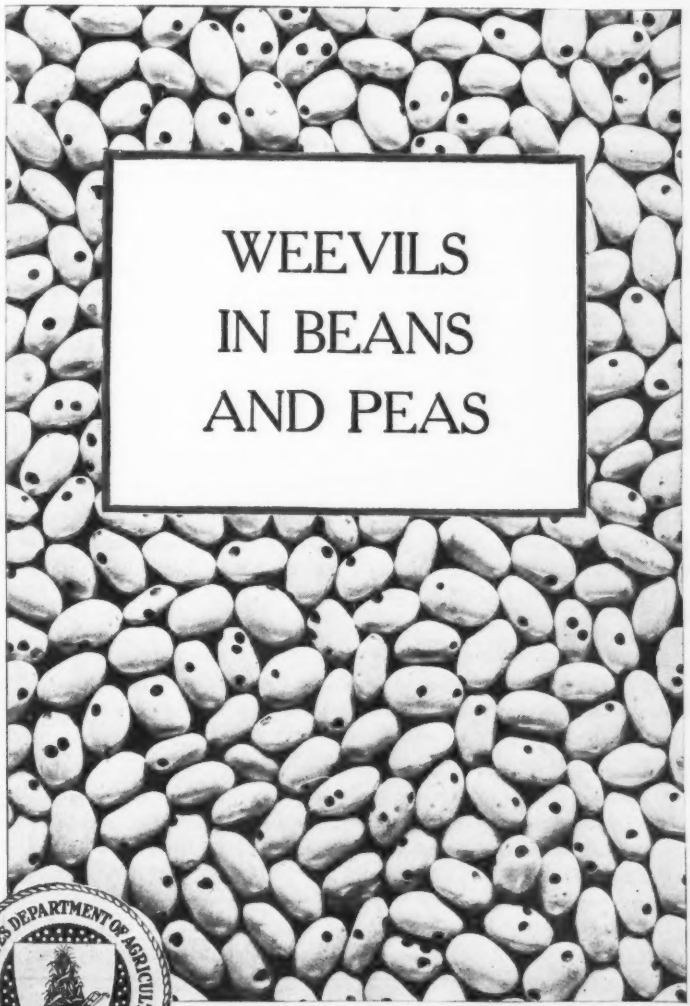

WEEVILS IN BEANS AND PEAS

XUM

BEANS, peas, and cowpeas are often damaged seriously in storage and in the field by weevils. Velvetbeans and soybeans are rarely infested in this country. Bean, pea, and cowpea weevils not only destroy an important part of the Nation's food in the form of leguminous crops but are responsible for a curtailment in the acreage planted to these crops. They never attack corn and wheat.

A large percentage of the initial infestations occurs in the field, where the parent weevil lays her eggs on or in the pods. The grubs, upon hatching, burrow into the seeds by gnawing a hole no larger than a pinprick. This entrance hole is usually not observed; hence the often expressed erroneous belief that the adult weevils that eat out from the seed, leaving behind a round hole about one-sixteenth of an inch in diameter, have "developed from the germ."

The most injurious bean and cowpea weevils in the United States can breed generation after generation in dried seeds in storage. During the hottest summer weather one generation requires about 1 month for development. Female weevils may lay as many as 50 to 58 eggs a day, though the average total number of eggs laid by an individual during her life is about 100. Infested seeds in bulk usually heat, thus producing temperature and moisture conditions most favorable for the rapid development and vigorous breeding of weevils.

Infestations in beans and peas can be quickly and effectively stamped out by fumigation with any of the fumigants commonly available, or by means of heat or cold storage. Weevils can be prevented from breeding in storage by mixing dust or air-slaked lime with the seeds. Concerted action by a community of growers has been known greatly to reduce weevil infestations and is recommended unreservedly for consideration in commercial bean-growing areas.

For the direct control of the pea weevil, apply dust mixtures containing 0.75 percent of rotenone to canning and garden peas—and, where practicable, to peas grown for seed—within a few days after the peas start to bloom.

In brief: Plant weevil-free seeds, harvest as soon as possible, treat to kill weevils, and store where seeds can be protected from reinfestation by weevils spreading from infested seeds.

Preventive and remedial measures are described fully in this bulletin.

Washington, D. C.

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WEEVILS IN BEANS AND PEAS

By E. A. Back, *principal entomologist, Bureau of Entomology and Plant Quarantine*[1]

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SERIOUS LOSSES CAUSED BY BEAN AND PEA WEEVILS

Bean and pea weevils are by no means new pests. They belong to a class of insects that cause farmers and merchants of this country an annual loss of many thousands of dollars.

The pea weevil is one of the major pests of garden and field peas, whether grown for canning, for seed, or for dry edible peas, throughout a large part of the United States where these crops can be grown. According to data compiled by workers of the Bureau of Entomology and Plant Quarantine, it is estimated that during recent years, particularly during the period 1934–37, the pea weevil has caused an annual loss of approximately $600,000 in the crops of peas grown for seed or for canning in the States of Idaho, Oregon, and Washington alone. These losses have consisted principally of (1) infested dry peas, which have to be discarded; (2) the cost of removing infested peas from seed peas or dry-pea products; (3) the abandonment or destruction of badly infested pea fields or portions thereof to avoid including weevily peas in the canned or processed product; (4) the expense of determining the locations of fields, or parts of fields that should be abandoned; and (5) the cost of material, labor, supervision, and machinery for applying insecticides.

[1] The original edition was prepared while the author was in charge of the Division of Stored Product Insect Investigations of the former Bureau of Entomology. In the reorganization of the work with the establishment of the Bureau of Entomology and Plant Quarantine, this Division was discontinued, and the author has since been associated with the Division of Insects Affecting Man and Animals. This revision was prepared in collaboration with D. J. Caffrey of the Division of Truck Crop and Garden Insect Investigations.

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The bean weevil has been one of the principal factors in discouraging the production of field beans in many districts of the South and Southwest and in California, except at the higher altitudes. This pest is considered one of the worst enemies of all types of garden beans grown in this territory. The southern cowpea weevil is commonly found associated with the bean weevil as a pest of cowpeas, beans, peas, and other seeds in the southern part of the territory infested by the bean weevil. The cowpea is now recognized as one of the most valuable cover crops for enriching the soil; and agriculturists claim that one of the important limitations to its more general use for this purpose and for fodder and human consumption is the susceptibility of cowpea seed to infestation by the southern cowpea weevil and the bean weevil. These two weevils are an important factor in maintaining the high cost of cowpea seed and in the consequent curtailment of the use of this plant as a soil builder, even in years of normal production. Because of the rapidity with which these weevils destroy cowpeas grown for human consumption, seedsmen and merchants have tended to view with suspicion all cowpeas grown in sections known to be badly infested by these insects, and this attitude has had a depressing effect on the production of cowpeas for food. Instances of losses sustained from the bean weevil and southern cowpea weevil are numerous. For example, it is reported that in 1926 these two species cost the growers of beans and cowpeas between $1,000,000 and $1,250,000 in San Joaquin, Stanislaus, and Merced Counties, Calif. Recorded losses to individual growers of these crops from weevil damage range from $75 to $8,000 a year.

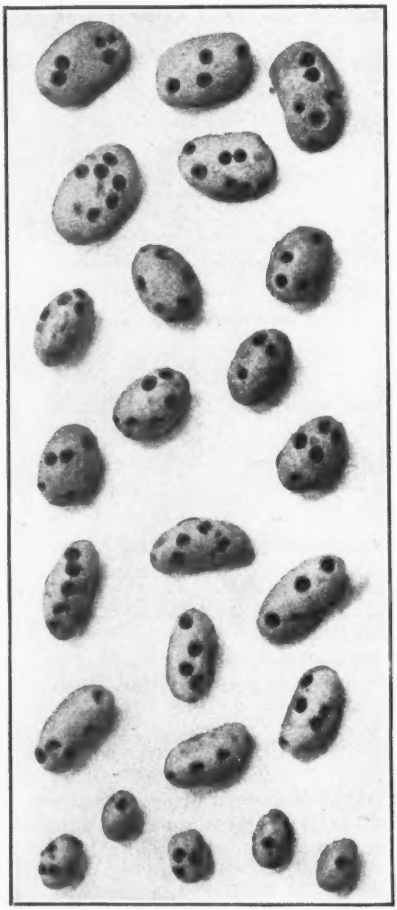

FIGURE 1.—Navy beans showing the emergence holes of weevils. Each of these holes is made by a weevil as it matures in the seed and leaves by cutting out a piece of the skin. All except the five small beans at the bottom have been injured by the common bean weevil. The five small beans were grown in Central America, and have been infested by the Mexican bean weevil. About natural size.

Since the introduction from Europe of the broadbean weevil into California about 1909, the damage caused by this pest is estimated

to have caused a reduction of from 25 to 75 percent in the acreage formerly planted to Windsor beans, also known as broadbeans or horsebeans.

It is evident from the foregoing that the various species of weevils attacking beans and peas should be charged not only with the damage they cause leguminous foods actually produced, but also with the indirect losses to the country due to the reduction in the areas planted to beans, peas, and cowpeas.

LOSSES OFTEN DISCOVERED TOO LATE

Injury to edible legumes usually is observed first after the crop has been in storage for several months. Many believe that once the crop has been harvested it needs no further attention. Seeds put away at harvesttime are sometimes not examined again until the following planting season, when they are found "buggy" or "weevily" and badly damaged. The town or city gardener has proudly put away for winter consumption beans grown during the previous summer, only to find them worthless as food and full of holes and honeycombed by grubs when later he opens the jar or sack in which they have been stored. Wonder is often expressed that seeds apparently sound when put away for the winter, and kept always well covered, should be found later injured by weevils. Because small round holes (see title page and fig. 1) and weevils appear later in seeds seemingly perfect when harvested, a belief is current among many that bean and pea weevils develop spontaneously from the germ of the seed. That there is no foundation for such a belief is shown by the facts following.

HOW BEANS AND PEAS BECOME INFESTED

Bean and pea weevils, like many other insect pests, pass through several marked changes in form and habits before reaching maturity. The story of development is shown in figure 2. The weevil that is seen crawling about among the seeds is the parent insect. Many of these fly from the storage room or house to the fields where beans and peas (fig. 3) are growing. As the bean and pea pods develop, the mother weevil lays whitish eggs, either on the outside or within the pods. These eggs are so small that they are often not noticed for they appear as mere white specks upon the pods. From these eggs there hatch white grubs that burrow their way through the pod into the soft developing beans or peas. Because these grubs are so very tiny, the holes through which they enter the seeds are too small to be seen unless one searches for them with a microscope. Usually beans become infested first when they are nearly or quite full-grown. As the seeds expand and harden in the final ripening process the holes in the skin through which the grubs entered become less and less easy to find. The wound in the skin either becomes entirely healed over or remains similar in appearance to a small pinprick.

Since beans and peas mature much faster than the weevil grubs within them, it happens that the weevil grubs are comparatively small or little developed, in many instances, when the crop is har-

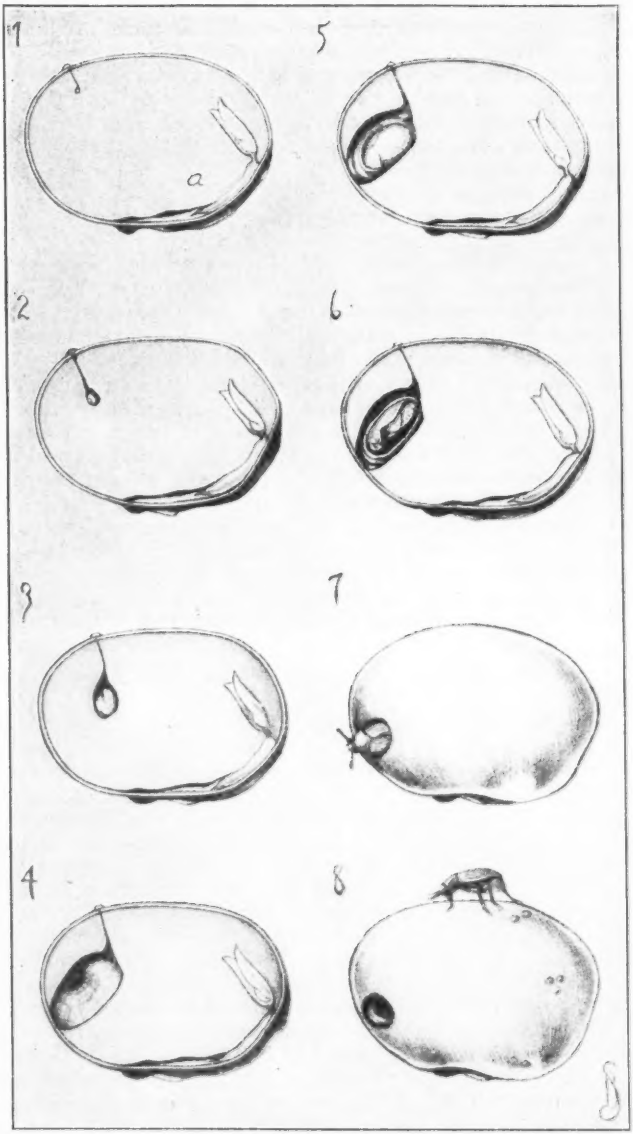

FIGURE 2.—Life cycle of the southern cowpea weevil: 1, Cross section of seed showing embryo or germ at *a*, and on upper left side an eggshell and the small burrow made by the newly hatched grub from the underside of egg into the seed; 2, 3, and 4, larva or grub in different periods of growth, the larva of 2 being full-grown; 5, pupa, or resting stage, which is intermediate between the larva and the adult; 6, side view of beetle within the pupal cocoon ready to gnaw the round hole in the seed coat so it can crawl out of the seed; 7, beetle has eaten a circular hole in the seed coat and is crawling out (note that this emergence hole is some way from the point of entry); 8, female beetle laying eggs on the seed.

FIGURE 3.—Field peas in bloom. Adult pea weevils begin laying their eggs on the young pods in the field. Photograph by Vinal.

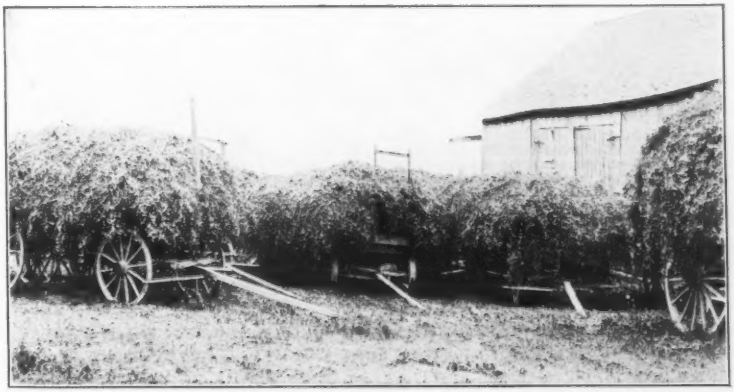

FIGURE 4.—Wagon loads of field peas brought to mill to be threshed. Remember that the pea weevil, the broadbean weevil, and the lentil weevil are the only weevils mentioned in this bulletin that cannot breed in dried seeds in storage. For this reason any infestation by these weevils occurs only in the field while the crop is maturing; hence the weevil grubs are in the seeds at the time they are harvested, shelled, or threshed, and any treatment at that time, if done thoroughly, will prevent the development of holes in seeds resulting from the emergence of adult weevils.

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vested (fig. 4) and placed in storage. Thus many seeds that appear outwardly in excellent condition in reality have weevil grubs hidden away in their interior, as shown in figure 2.

WHERE WEEVILS IN STORAGE COME FROM

At harvesttime the weevil grubs developing from eggs laid on or in the pods of beans, peas, or cowpeas in the field may have devoured very little of the seed contents, but if the seeds are stored in a warm place, or in a climate where the weather is sufficiently warm, they continue to feed and become well-grown. When well-grown, they have eaten out of the seed contents a cavity somewhat larger than themselves, extending outward to, but not puncturing, the skin of the infested seed (fig. 5). The grub then changes or transforms into the pupa (figs. 9, *c*, and 14, *c*) and later into the adult. This adult has a pair of sharp jaws which it uses like a pair of scissors to cut out a circular flap (fig. 6) in the seed skin, thus making the small round hole which is, to most gardeners, the first evidence that insects are in the seed. Through these openings the adults crawl out and by their presence in sealed jars and other containers cause much concern.

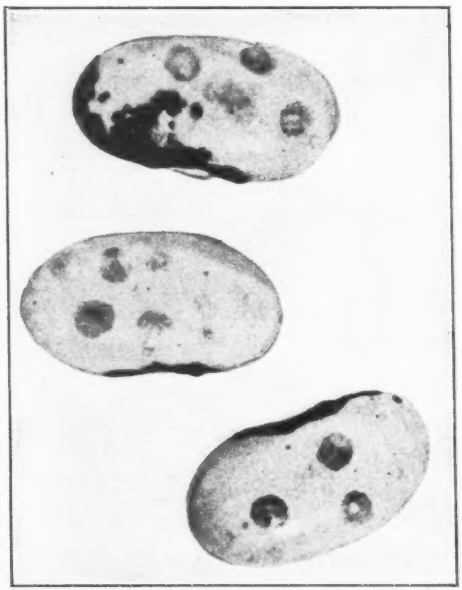

FIGURE 5.—Beans in which the bean-weevil grubs have become full grown and have eaten out from the interior of the bean to, but not puncturing, the skin. As they transform to adult, each insect darkens, and this dark color shows through the thin skin and makes the dark, sometimes bluish, translucent spots in beans. Such spots indicate that seeds are infested. It should be remembered that while the grubs are still growing they are white, and seeds do not indicate their presence by any such dark spots as shown above. Three times natural size.

THE TWO GROUPS OF WEEVILS

The principal kinds or species of weevils known to attack beans, peas, cowpeas, and similar crops may be divided, roughly, into two groups as follows:

Group 1, consisting of the pea weevil (*Bruchus pisorum* (L.)), the broadbean weevil (*B. rufimanus* Boh.), and the lentil weevil (*B. lentis* Boh.), attacks the seeds in the field only, at a time when the seeds are in a green growing condition. These species cannot reproduce on dry seeds and will die without leaving any progeny unless they can find growing host plants on which to lay their eggs. They have only one generation each year.

Group 2, consisting of the bean weevil (*Acanthoscelides obtectus* (Say)), the southern cowpea weevil (*Callosobruchus maculatus* (F.)), the cowpea weevil (*B. chinensis* (L.)), and the Mexican bean weevil (*Spermophagus pectoralis* Say), not only attack the seeds in the field but also continue to reproduce several successive generations each year in the dried seeds, usually in storage, when temperature conditions are suitable (fig. 7). Because each generation of these species of weevils injures the seed for planting and for food, steps should be taken to kill, at harvest time, such weevil grubs as may be in the seeds and thus prevent further losses. If this is not done the seeds become honeycombed by the feeding of successive generations of the grubs and may be reduced to a powder (fig. 8). Since the bean weevil, the southern cowpea weevil, the cowpea weevil, and the Mexican bean weevil breed in dried seeds, it is especially important not to store

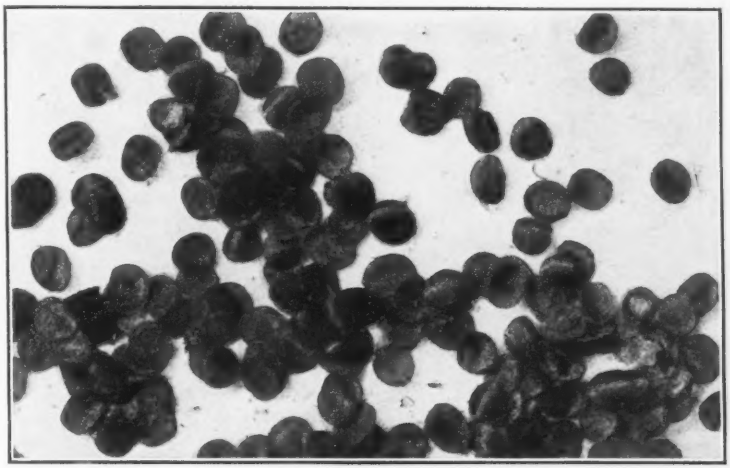

FIGURE 6.—In escaping from beans, peas, or cowpeas, or any host, weevils leave behind them the small round holes familiar to all. In making these holes they use their jaws to cut around the dark spots shown in figure 5 and then push away the circular flap of skin just as one opens a tin can of preserved fruit with a can opener. These circular bits of skin, shown above, about four times natural size, may be found among the seeds.

uninfested seed near seed that contain these weevils, for they will spread rapidly and soon infest all exposed seed in the vicinity.

GENERAL DESCRIPTIVE FACTS

The bean and pea weevils of the United States, considered in this bulletin, are all very small. None of them are more than one-eighth to one-fifth of an inch long. They are dull-colored, with markings of white or black. For the general shape, size, and arrangement of these markings, see figures 9, 12, 14, 15, 18, and 20. Their eggs are from one-fiftieth to one-twenty-fifth of an inch long, white or whitish, and appear as specks (figs. 16 and 17) when laid on beans and cowpeas in storage.

The larvae, or grubs, naturally are very small when first hatched and are white. After feeding, they become somewhat maggotlike

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in general appearance, being nearly cylindrical, fleshy, distinctly wrinkled, more or less curved in outline, and not more than one-fourth of an inch long and usually less.

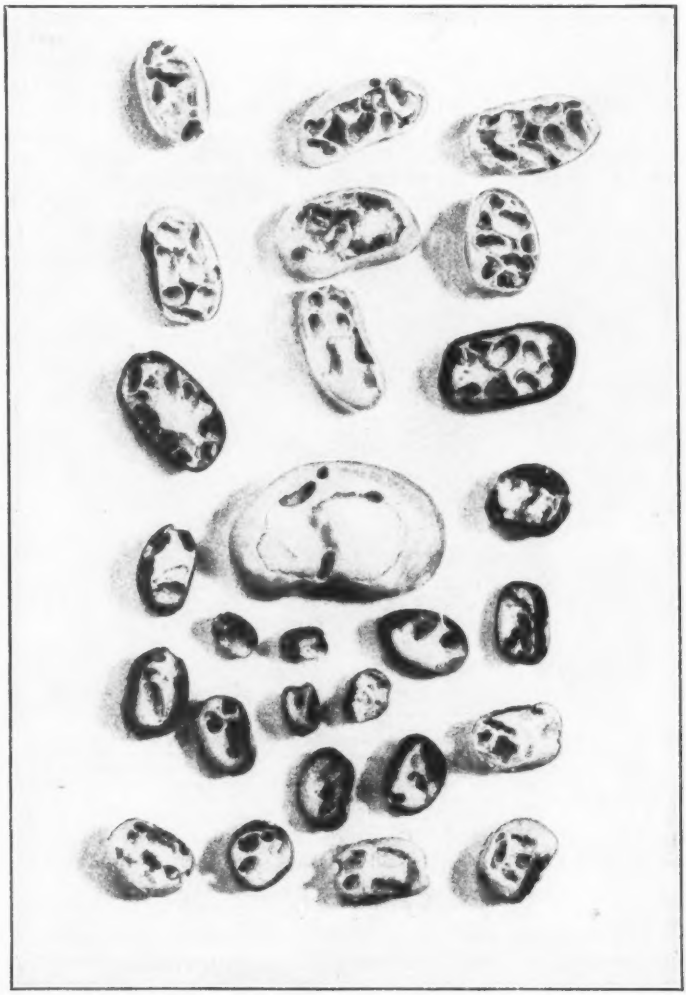

FIGURE 7.—Various types of beans and cowpeas cut lengthwise to show how severely they may be damaged by bean and cowpea weevil grubs. Such beans and cowpeas are not fit for human food. Slightly enlarged.

By the time the grub has become full-grown it has eaten out in the seed contents a cell in which to transform to the pupa or chrysalis. Before transforming, it secretes a substance which hardens into a white, filmy cell about itself, and this serves to protect the helpless

pupa while the changes making it an adult are taking place. For the general shape and appearance of the grub and pupa see figures 9, 14, 15, and 18. The pupal cells are shown in figure 22. For the general life cycle see figure 2.

FIGURE 8.—Leguminous crops may be reduced to a powder by the continued feeding of weevil grubs. In the bottom of sacks or boxes in which weevily beans or cowpeas are held for a long time one finds quantities of dead weevils and the powdered remains of the seeds such as are shown above. About natural size.

WEEVILS THAT ATTACK SEEDS ONLY IN THE FIELD

THE PEA WEEVIL

The pea weevil is one of the most important insect pests of the field or garden pea. It now occurs over almost the entire globe wherever peas are cultivated. Serious damage to garden peas in Pennsylvania, New Jersey, and southern New York was caused as early as 1748, and nearly all growers of garden peas are familiar with the exit holes that are made by the insects in dried seed (fig. 11).

Losses caused by the pea weevil are especially heavy in the case of garden and canning peas. Because close inspection is required to detect the occurrence of weevil grubs in green peas, even where moderately abundant, their presence only rarely comes to the attention of consumers. Such infested peas are considered unfit for human food, however, and are regarded as adulterated under provisions of the Federal Food and Drugs Act. In the case of seed peas the presence of the pea weevil seriously affects their germination, and large losses result because of the necessity of separating the weevily from the sound peas before they are fit for sale. When dried peas are offered for human consumption the presence of the pea weevil therein renders such products liable to seizure by health officials on account of contamination.

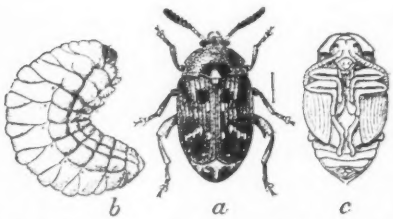

FIGURE 9.—Pea weevil; *a*, Beetle; *b*, larva or grub; *c*, pupa. The line to the right of the adult (*a*) represents the actual length of the beetle, and the sizes of the larva and pupa are in proportion. (Chittenden.)

The pea weevil is a small grayish or brownish-gray beetle about a fifth of an inch long. It is marked with black and white spots as shown in figure 9. The short line to the right of the adult in the illustration gives the actual length of the beetle. The adults appear on the vines when the peas come into bloom. They feed principally on the petals of the pea flowers and on the succulent tissues of the stems and pods, as shown in figure 10. While they eat holes in the petals and gnaw out long narrow slits in the stems, they do not appear to damage the plants materially, as the damaged flowers produce normal pods and the slits in the stems soon heal over and do not cause wilting.

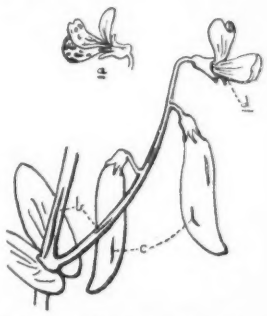

FIGURE 10.—Plant of garden pea showing, at *a*, holes in blossom where pea weevil beetles have fed; at *b*, slits in stem; and at *c*, cuts in pods made by the feeding beetles. The beetle finds its favorite shelter at *d*. (Skaife.)

The adults show a strong tendency to remain dormant during the season of the year when growing peas are not available for attack. Thus while certain beetles having access to pea plants lived only 4 or 5 weeks, others were found alive in dried seeds 14 months after the seeds were gathered. The female weevils lay their yellowish eggs singly upon the surface of the pods, to which they attach them with a peculiar viscid secretion. The young grub, upon hatching, gnaws, through the pod and burrows into the seed, where it does practically all its feeding. While as many as six young grubs have been found in single seeds, it is seldom that more than one matures and emerges (fig. 11).

The length of time required for the eggs to hatch and for the grub or larva to mature to the adult varies with the climate. In the District of Columbia adults have appeared as early as July 21. Others have been reared as late as the middle of August. A very considerable

portion of the beetles mature and leave the seeds in the latter part of the summer in the latitude of Washington, D. C., but farther north and in higher altitudes the adults remain in the peas until the following spring, when they emerge in storage or are planted with the seed, or they emerge from the seed by harvesttime and seek hibernating quarters. Adults sometimes emerge in such numbers during the threshing of the peas in certain northern field infestations as seriously to annoy the workmen. It is largely in the adult stage that the weevil passes the winter, hibernating either in secluded spots in fields or buildings or in the pea seed itself. The pea weevil has only one generation a year and cannot reproduce in dried peas.

FIGURE 11.—Garden peas showing exit hole of the pea weevil. Note that only one weevil develops in a single pea. One seed has been sectioned to show cavity made by grub. Twice natural size.

THE BROADBEAN WEEVIL

The broadbean weevil closely resembles the common pea weevil, being about the same size, one-fifth of an inch long, and of similar appearance. It can, however, be readily distinguished by its much narrower thorax and fainter markings, as a comparison of figures 9 and 12 will show.

The broadbean weevil (fig. 12), sometimes called the European bean weevil, is common and destructive in Europe and northern Africa. While it feeds upon various sorts of beans and peas, it appears to prefer the broad or Windsor beans (fig. 21). Although it has been found from Canada to Texas in Windsor beans imported into various parts of this country, the first discovery of its definite establishment in the United States was made in 1909 at San Luis Obispo, Calif., where it was injuring the broad or Windsor bean (*Vicia faba*) grown for stock feed.

FIGURE 12.—Adult of the broadbean weevil. Enlarged six times. (Chittenden.)

Since then, and up to 1920, it has spread to include the coastal counties of California, from Sonoma to San Luis Obispo, besides San Benito, Santa Clara, Alameda, San Joaquin, Sacramento, Yolo, and Napa. Practically every broadbean entering a New York warehouse is more or less damaged by this pest. A single grub in its development consumes approximately 3 percent of the bean. Sometimes as many as six weevils develop in a single bean. Beside the actual amount of seed consumed, there must be considered the frass of the insect left behind in the seed, and this still further reduces the value of the crop. An infestation of over 15 percent bars any lot of beans from shipment under the Federal pure food law. It has been stated that of the entire broadbean crop of California for the years

1916, 1917, and 1918, 31.21, 18.01, and 43.08 percent, respectively, were above the allowed limit of weevil infestation, and therefore could not be shipped unless hand-picked. In 1916 the average percentage of infestation for the entire 1916 crop in the Halfmoon and Gilroy regions was above the 15-percent limit, while the same was true for the Sacramento and Halfmoon districts for the 1918 crop. After a campaign of seed fumigation in San Mateo County during 1918, 1919, and 1920 it was reported that the percentage of the broadbean crop infested above the tolerance limit was reduced from 43 percent in 1918 to 21 percent in 1919 and to 17.8 percent in 1920. Since beans uninfested, or infested less than 15 percent, were worth during these years from 5 to 6 cents per pounds, and others only 2¼ to 3 cents, it is easy to appreciate the dollars and cents value of concerted action among growers in applying cheap but effective remedial measures.

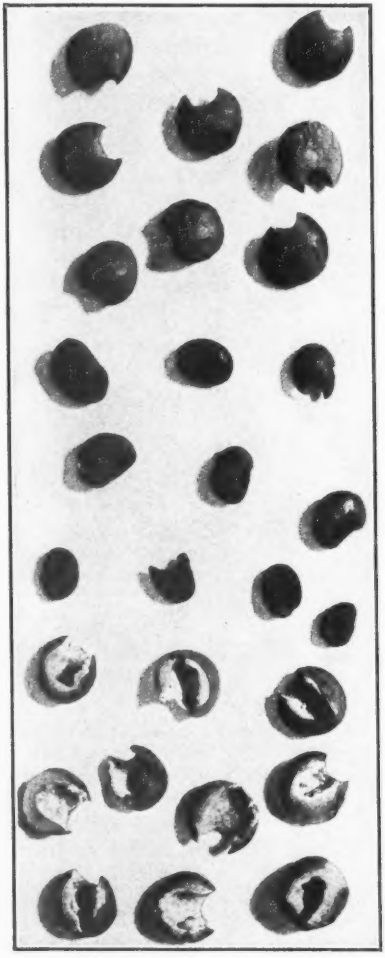

FIGURE 13.—Lentils of two varieties showing injury by the lentil weevil. While only one lentil weevil matures in a single seed, it is capable of practically destroying that seed, as indicated by the sectioned seeds at the bottom of the illustration. Somewhat enlarged.

The following biological facts are taken from a report of experiments conducted at Alhambra, Calif. The egg stage of the broadbean weevil lasts from 9 to 18 days, the larval stage from 10 to 15 weeks, the pupal stage from 7 to 16 days, and the beetle lives from 1 to 8 months. The eggs are laid on the green bean pods in the field from the middle of March to the middle of May; the larvae reach maturity from August to October, while the adults can be found from August to the following June. The broadbean weevil has but one generation each year and cannot start new generations in dried seed in storage; that is, such beetles as emerge from the seeds in storage have developed exclusively from eggs laid in the field upon the green pods and can do no further injury in warehouses.

THE LENTIL WEEVIL

The lentil weevil is not known to be established in this country at the present time, although it has been found repeatedly in imported lentils from Europe. It is an enemy of the lentil crop in middle and southern Europe, Egypt, and Syria. Since lentil growing is on the increase in this country, it is hoped to keep this pest from becoming established in North America.

The lentil weevil, only one of which matures in a single seed, resembles somewhat the pea weevil but is only about an eighth of an inch long. Like the pea and broadbean weevils, it has but one generation a year. The emergence holes and injury caused by this weevil are shown in figure 13.

WEEVILS THAT ATTACK SEEDS IN FIELD AND IN STORAGE

THE BEAN WEEVIL

The bean weevil is one of the most formidable enemies to the culture of beans in the United States as well as in many other countries. It occurs in nearly every State and in the Territory of Hawaii, and is generally distributed throughout Mexico, Central America, and South America. It has been found in beans imported from southern Europe, Persia, India, China, Algeria, South Africa, Madeira, the Azores, and the Canary Islands. Commerce has carried it to all the larger markets of the world. So severe is its attack in the warmer sections of this country that dried beans for seed and for food are grown mostly in the more northern States and California. In the South and Southwest and in California bean growing is made very difficult, if not rendered unprofitable, by the unmolested increase of the bean weevil.

The bean weevil is smaller than the pea weevil, being only about an eighth of an inch long. It is shaped and marked as illustrated in figure 14. The adult, or beetle, is so coated with fine hairs that it appears brownish gray or olive color. Unlike the pea weevil, the bean weevil not only can develop in growing beans in the field, but can also breed generation after generation in dried beans in storage.

The adults may live as long as 9 weeks, though usually 2 weeks represents their more normal length of life during the active season. Of course, adults may remain alive in a dormant condition for several months in dried seeds during cold weather.

The female weevils may fly from storage quarters early in the summer and from then on may be found upon the bean plants. While the weevils lay their eggs in largest numbers through cracks in the pod that develop during the drying out of the pod, the female has been observed to gnaw holes in green pods and to lay her eggs through such holes. Eggs are never glued to the outside of the pod as is the habit of several other species of bean and pea weevil. In storage the eggs are laid singly and loosely (i. e., unattached) among the seeds. As many as 59 eggs may be laid by a single female in 1 day, and a total of 209 eggs during her life. As many as 67 eggs have been found laid through a crack in a bean pod.

As many as 28 weevil grubs have been found in a single bean. All varieties of garden beans are attacked, even lima beans being severely damaged during 1920 and 1921 in New England.

Experiments have demonstrated that the eggs of the bean weevil require from 5 days in the hottest weather to 20 days at a cooler temperature to hatch, and that the larvae or grubs become full grown in from 11 to 42 days and the pupae in from 5 to 18 days, according

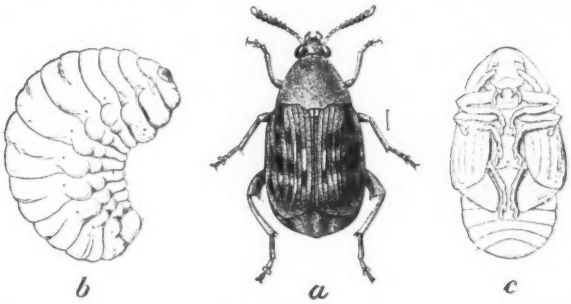

FIGURE 14.—Bean weevil: *a*, Beetle; *b*, larva or grub; *c*, pupa. The short line to right of the beetle (*a*) represents its real length. (Chittenden.)

to the temperature. It requires 21 to 80 days at least, according to the season and locality, for a generation of the bean weevil to develop. In the District of Columbia there may be as many as six generations a year. The warmer the climate the greater the number of generations and the consequent damage done by the grubs.

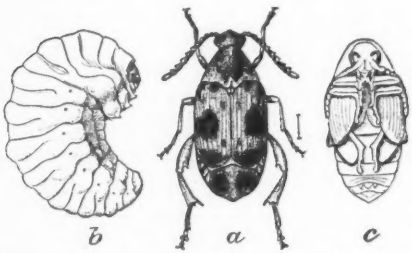

FIGURE 15.—Southern cowpea weevil: *a*, Beetle; *b*, larva or grub; *c*, pupa. Six times natural size. (Chittenden.)

In a climate similar to that of the District of Columbia and adjacent parts of Maryland and Virginia, adults of the first generation started in the field begin to emerge as early as October. If the fall is early and the seeds are stored in a cold place no adults may emerge before the following spring. If seeds are stored in a warm place, adults may emerge at any time during the winter. After emergence in storage the adult females lay eggs either on the beans or on the sides of the receptacles in which the seeds are stored

THE SOUTHERN COWPEA WEEVIL

The southern cowpea weevil is a major pest of cowpeas in the United States. The female is about one-eighth of an inch long and is distinguished by four black spots upon the wing covers as shown in figure 15. In 1885 this species was found swarming on blackeye cowpeas from Texas exhibited at the Atlanta Cotton Exposition. Since then it has spread throughout the Southern States, California, and as far north as Iowa, and is probably present wherever cowpeas are grown.

The cowpea is its favorite host food, although peas and beans are attacked (figs. 16, 17, and 19). While female weevils may lay eggs upon the pods and seeds in the field, and hardly a crop of cowpeas matures in the South without an abundant infestation, this weevil breeds most prolifically in dry seeds in storage. It does not lay its eggs loosely among the seeds as does the common bean weevil, but glues them to the seed, as shown in figure 17, and the presence of these white specklike eggs in any consignment is always an indication of infestation.

The adult weevil lives, on an average, about 15 days. While the average number of eggs laid per female in certain experiments was 82, as many as 196 eggs were laid by one female. Usually the largest numbers of eggs are laid during the first few days of adult life. One female weevil laid 22, 15, 15, 14, 6, 13, 2, 11, 6, 0, 0, and 2 eggs respectively on the first 12 days after leaving the seed in which she developed. Death soon follows the completion of egg laying. Eggs hatch in from 4 to 6 days during warm summer weather. During the cold winter weather in Texas eggs require from 25 to 37 days for development. The percentage of eggs that hatch in winter is very small, while that in summer is very high. The length of the larval stage ranges from 9 days to more than 8 months. During warm summer weather from 17 to 22 days is usually required. Larvae emerging from eggs laid late in the fall require long periods for development and pass the winter as dormant grubs within seeds in cold warehouses. Taking the egg, larval, and pupal stages into consideration, it is safe to say that development requires from 30 to 48 days during warm weather.

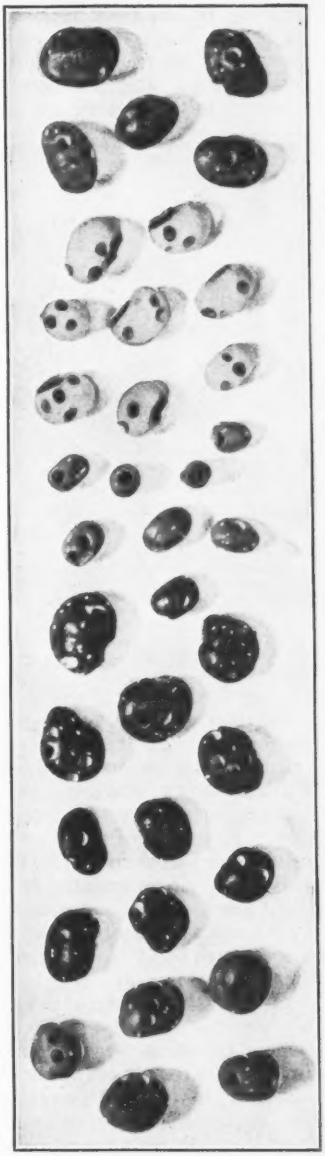

FIGURE 16.—Different varieties of cowpeas showing infestation by southern cowpea weevil. Seed about natural size: the white specks on the seeds are the eggs of the weevil.

THE COWPEA WEEVIL

The cowpea weevil (fig. 18) is a foreign species first described from

China. It has been reported from every continent and is likely to be found in any commercial center. From 1898 to 1911 it was known to be well distributed and often abundant throughout the Gulf Coast States and even as far north as Washington, D. C. It is now a pest of minor importance in the United States, where it has not been observed for some years. Although it prefers cowpeas, it may attack the common pea, pigeon pea, lentil, chickpea, mung bean, and the common white bean.

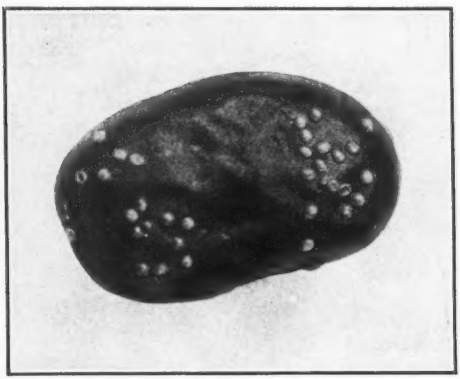

FIGURE 17.—A cowpea seed showing eggs of the southern cowpea weevil. The eggs of bean and pea weevils vary in shape but are always small, ranging in length from one-fiftieth to one twenty-fifth of an inch. They are white or whitish, and may be laid anywhere upon the outside of the seed, as indicated here, or in cavities in the seed made by a previous generation of grubs, or on sides of containers such as burlap sacks, barrels, etc. The eggs can be distinctly seen on seeds, as tiny white specks. Five times natural size.

The adult weevil is about an eighth of an inch long and may be distinguished from other weevils discussed in this bulletin by elevated ivorylike spots near the middle of the body, shown in figure 18. Its biology is similar to that of the southern cowpea weevil. During very hot weather a generation may mature in 21 days (egg, 4 days; larva, 13 days; pupal stage, 4 days). This period is lengthened by cooler weather and may approximate 3 or 4 months during winter weather. This insect glues its whitish eggs to the surface of the seeds, as does the southern cowpea weevil, and is capable of breeding indefinitely in dried seeds in storage.

The adults live on an average 5 or 6 days during the hottest weather and as many as 40 days during the winter months in the Gulf Coast States. Activity is likely to cease entirely at a mean temperature of 50° F., or below, when the insects will seem dead to all outward appearances and only resume activity when the weather becomes warm. While the immature stages may be passed in as few as 16 or 17 days, 21 days is closer to the normal time required during hot summer weather. The longest period for larval development yet recorded is 88 days, from December to March, in Texas, when the temperature ranged from 22° to 86°. There may be from 8 to 10 generations a year in the Gulf Coast States.

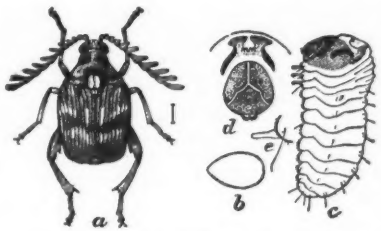

FIGURE 18.—Cowpea weevil: *a*, Adult male; *b*, egg; *c*, postembryonic larva; *d*, front view of head of same, *e*, thoracic leg of same; *a*, six times natural size; *b–e*, more enlarged. (Chittenden.)

THE MEXICAN BEAN WEEVIL

The Mexican bean weevil is an inhabitant of South and Central America and is occasionally found at our Pacific and Atlantic ports, infesting beans imported from these countries. It attacks beans and cowpeas. It breeds continuously in dried seeds and is capable of being as injurious as the common bean weevil, as indicated by the five small beans affected by this pest, shown at the bottom of figure 1. For the size, shape, and marking of this insect, see figure 20. The adult lays her eggs upon the seeds to which they are stuck by a cement similar to that used by the southern cowpea weevil (fig. 17). While occasionally intercepted at ports of entry for many years past, this species does not appear to have become established in the United States.

FIGURE 19.—Chick peas affected by the southern cowpea weevil. Compare these with the two sectioned chick-peas at the bottom of figure 22. Twice natural size.

WHY WEEVILS LIMIT ACREAGE PLANTED TO CERTAIN LEGUMINOUS FOOD CROPS

It has been pointed out already that infestation nearly always takes place in the field while the crop is maturing. With garden or Canada peas, lentils, and broad or Windsor beans infested with the pea weevil, the lentil weevil, and the broad bean weevil, respectively, this is always the case, for these weevils never breed in dried seeds. Other species that breed in dried seeds, as well as in the field, may spread in storage to uninfested seeds and badly infest them. It is generally known that the colder the winters the shorter the growing season and the fewer the bean and pea weevils that survive the cold of winter and are ready to fly to the fields to start the infestation of the growing crop by laying eggs on the pods. The farther south one goes the more mild the winters become, the longer the growing season, and the greater the number of weevils that can live through the winter.

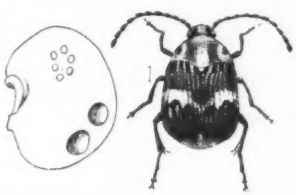

FIGURE 20.—Mexican bean weevil: Adult weevil with line to left indicating actual length. Infested bean to left showing two emergence holes and six eggs. (Chittenden.)

As far south as the District of Columbia and the adjacent tidewater country of adjoining States, therefore, overwintering weevils attack the beans and peas in large numbers and succeed in years favorable for them in laying so many eggs upon the pods that each developing bean becomes affected and often may support as many as 20 to 28 weevil grubs. Because of the long, warm falls and the length of time the plants are allowed to remain in the field after the crop has ripened, either standing in the ground or pulled and stacked, these grubs are given every opportunity to develop into adults or at least to become very well grown in an unusually large number of cases, and therefore they cause greater damage than do weevils in beanfields farther north. Thus beans grown in latitudes south of New York City, except in higher altitudes, as in the mountainous regions of the Alleghenies, become more infested than those grown north of that latitude. As

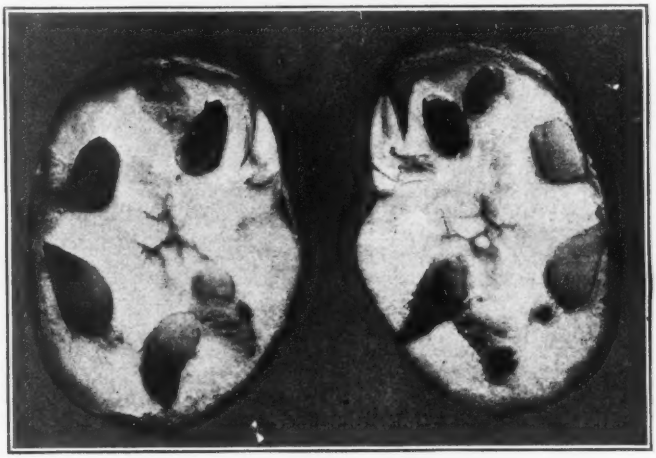

FIGURE 21.—A broad, horse, or Windsor bean, cut open to show the damage caused by grubs of the broad-bean weevil. Only one generation of this weevil occurs each year. As each cavity represents the feeding of one grub, this bean is badly affected. Considerably enlarged.

weevils in beans are not killed so easily as are many other insects and as their presence in numbers in beans is objectionable whether beans are grown for food or for planting, even when the grubs have been killed (fig. 22), the growing of beans on a commercial scale for dried seeds has largely been given up in our more southern latitudes. This explains the question often asked why beans and peas grown in portions of California, Michigan, New York, Washington, Oregon, or Idaho, or even in Canada, find their way into our southern markets, which one would expect to be supplied by southern-grown beans and peas. Practically all the dried beans grown for seed and for food are grown in these Northern States, where the bean weevils are not able, because of climatic checks, to cause so much damage. Of course weevils do not affect the growing beans to be eaten green, as string beans or green shelled beans, for such beans either are not, at the time of gathering, infested; or if infested, the grubs are too small to interfere with the food value of the beans.

GERMINATION AFFECTED BY WEEVIL ATTACK

The germination of beans, peas, and cowpeas is likely to be seriously affected by the development of weevil larvae. If the embryo is destroyed by the larva or if too much of the bean substance is eaten, the seeds cannot grow.

Beans as badly infested as those shown in figures 1, 7, and 23 are worthless for planting. As the young bean or pea plant depends upon the food stored in the seed to give it its start, the destruction of any portion of the seed by weevils lessens by so much the vigor of the plant. In one experiment on record, only 50 percent of infested beans germinated, and of these 30 percent were so badly injured that they could not develop into normal plants. The smaller the seed, the greater proportional damage a single weevil grub can cause. One grub ruins a small cowpea seed (fig. 16) or a lentil (fig. 13), whereas it would not so seriously affect a large seed like the lima bean. The germination of broadbeans infested with 1, 2, 3, and 4 or 5 broadbean weevils was found to be reduced from a normal of 95.7 to 82.7, 72.7, 71.1, and 69.6, respectively. Of 50 garden peas infested by the pea weevil examined, 33 were found with the embryo wholly or partially destroyed, and in another case only 69 out of 275 infested peas had undamaged embryos or germs.

FIGURE 22.—Beans (six upper seeds) and chick-peas (two lower seeds). The skin of the beans has been removed to reveal the cavities eaten out by the bean weevil grubs. The grubs have been killed by fumigation and have turned black. Note the white paperlike cell or cocoon about each of the grubs. The chick-peas have been cut open to show how the larvae of the southern cowpea weevil can burrow to the very center of the seed. Slightly enlarged.

HEATING DUE TO INFESTATION

It is a well-known fact that beans and peas, as well as grains, will heat if insects become sufficiently abundant in them. In bean warehouses where the seeds are stacked, as shown in figures 25 and 26, centers of weevil infestation can be detected by walking past the tiers of sacks and allowing the hand to pass over the sacks. Experience soon makes it easy to detect heating sacks. Heating seeds also produce an odor quickly detected by experienced persons when they enter a warehouse after it has been closed for a few hours.

The ability of bean and pea weevils to produce heating of the seeds is of great importance. Were it not for this ability, owners could rest assured that if warehouses were open to outdoor temperatures below 50° F. no injury from weevils would take place. Certain weevils develop most quickly when the temperature ranges between 75° and 95°, and egg laying is greatly stimulated by these higher temperatures. At temperatures ranging from 75° to 95° the development of the southern cowpea weevil has been known to be completed in 18 days; hence heating caused by weevil infestation, with the accompanying increase in moisture content of the seeds, may result in an outbreak of weevils at a season of the year when least expected. The temperature of a 240-pound sack of chick-peas infested by the southern cowpea weevil may be raised by infestation to at least 103°. It is not uncommon in some warehouses to find a considerable number of sacks the temperature of which has been raised to over 80° or 90°. In one instance, when the daily maximum temperatures ranged between 50° and 58°, sacks within 2 feet of an open window registered

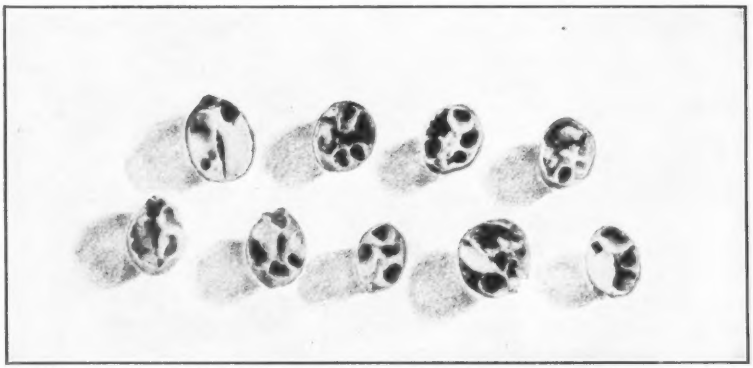

FIGURE 23.—Navy beans cut crosswise to prove how the bean weevil can ruin seeds for eating or planting. About natural size.

102°. The temperature in the spaces between heating sacks was raised in this warehouse from 58° to a minimum of 70° and a maximum of 78°. At 58° adult weevils were too cold to migrate, but at 70° to 78° they were very active and were spreading from heating sacks to surrounding sacks and laying eggs upon previously uninfested seeds.

This effect of heating, due to infestation, upon spread of injury from sack to sack, to say nothing of increase in infestation within the individual sacks during cold weather, should be understood by those holding beans and peas in storage; otherwise, serious losses may occur. Fumigation with hydrocyanic-acid gas (p. 30) kills the insects, reduces the temperature to normal, and stops the spread. Fumigation with any efficient fumigant will probably have the same result.

GENERAL METHODS USED FOR THE CONTROL OF WEEVILS IN BEANS AND PEAS

In applying methods for the control of the seven kinds or species of weevils discussed in this bulletin it must be remembered, as stated previously, that these species of weevils fall into two distinct groups;

that is, the first group, which consists of weevils that attack seeds only in the field, and the second group, which consists of weevils that attack seeds both in the field and in storage. Many of the methods of control, however, are nearly the same for both groups. These control methods may be summarized as follows:

(1) Plant weevil-free seed. Large numbers of weevils are able to escape from infested seeds and infest the growing crop.

(2) Harvest and thresh or shell all seeds from weevil-infested fields as soon as they are ripe, before weevil emergence occurs, and in order that the seeds may be more easily and cheaply treated to keep the weevil grubs from further feeding and maturing. Storing in the pod does not confine the weevils. The grubs continue their development and transform to adults in the unshelled as well as in the shelled seeds. The adult weevils can then gnaw their way out of the dried pods.

(3) Immediately after they are harvested, place the seeds in tight bags having at least 24 strands to the linear inch (fig. 28) in order to prevent the escape of such weevils as may emerge from the seeds within the bag and to prevent the species of weevils that attack dry seeds from gaining entrance to the bags.

(4) Fumigate infested seeds as soon as possible after harvest to prevent further development of the contained weevils.

(5) Eliminate all shattered seeds and other crops remnants that may remain on the field surface after harvest, by clean plowing, burning, pasturing with livestock, or any other available method that under local conditions will accomplish the utilization or destruction of these common sources of reinfestation.

(6) Feed to livestock, or plow under deeply and cleanly, or burn, or otherwise utilize or destroy, the straw or viner refuse from fields of peas, beans, or cowpeas before the weevils contained in any seeds have a chance to emerge and infest the new crop. In such refuse there are usually seeds that were missed during the threshing, shelling, or vining process.

(7) Clean up possible hibernating or overwintering quarters of weevils, adjacent to or near cultivated fields, such as brush-filled fence rows, abandoned orchards, and dilapidated fences and buildings.

(8) Beans, cowpeas, or peas stored on the farm, in warehouses, or in other storage places should be examined at frequent intervals and fumigated when necessary. In weevil-infested warehouses special precautions should be taken to keep the floors and cleaning machinery free from susceptible seeds, and general sanitary measures should be instituted to clean up all possible sources of weevil infestation.

(9) In combating the pea weevil, the general control methods discussed in the preceding paragraphs can be supplemented, in the instance of valuable crops, or in home gardens, by insecticide applications as described later in this bulletin.

(10) It should be emphasized that any remedy that lessens the number of weevils present in the field reduces the number of weevils that must be fought in storage, and similarly the use of proper control methods in storage reduces the number of weevils that must be combated in the field.

CONTROL OF THE PEA WEEVIL

IN PEAS GROWN FOR CANNING AND FOR THE GREEN PEA MARKET

Supervision Important

Supervision is an important factor in the success of a large-scale control program. When extensive operations along the lines suggested in these recommendations are to be undertaken it is important that the program be under the direction of a competently trained person who knows the scientific facts regarding the weevil and its habits. It should be the duty of this person to determine when and where to apply control measures on each field and to check the results of this control whenever possible.

Use a Dust Mixture Containing Rotenone

Experiments and extensive tests on a commercial scale conducted in Oregon, Washington, and Idaho in 1936 and 1937 have demonstrated that the pea weevil can be controlled in canning and garden peas by the application of dust mixtures containing rotenone derived from derris or cube. The mixture should contain not less than 0.75 percent of rotenone, with talc or some similar inert carrier used as a diluent. The recommendations that follow may require distinct modification in some cases.

RATE OF APPLICATION

From 20 to 25 pounds of the dust mixture per acre should give satisfactory results if applied with an efficient dusting machine. Where the infestation is particularly heavy, as in some border strip plantings, the use of an additional 5 pounds of the dust mixture per acre should give greater assurance of successful control of the pea weevil.

TIME AND NUMBER OF APPLICATIONS

The first application of the dust mixture should be made a few days after the peas start to bloom and before any pods have formed on the vines; otherwise the weevils may lay eggs on the young pods. Additional weevil populations may fly into some of the fields; in that event one to two additional applications may be necessary. The time of these later applications depends upon when the weevil population increases in the field. In most instances a 6- to 10-day interval between applications has been satisfactory.

AREA TO BE DUSTED

In general the dust mixture should be applied to any fields or parts of fields where weevils can be found by sweeping with an insect-collecting net. Since the pea weevil in migrating from hibernation quarters to the peafields has a tendency to infest the field edges first, it is possible to secure adequate control in each field by applying the dust mixture to a marginal strip of varying width. If the field contains 10 acres or less, it is advisable to apply the dust mixture to the entire field in order to obtain satisfactory results. For large-scale control campaigns, each field should be examined, and the parts of each field found infested should be treated with the dust mixture.

DUSTING EQUIPMENT

The control effected by applications of the dust mixture is increased by the use of dusters with hoods constructed over the dust nozzles.

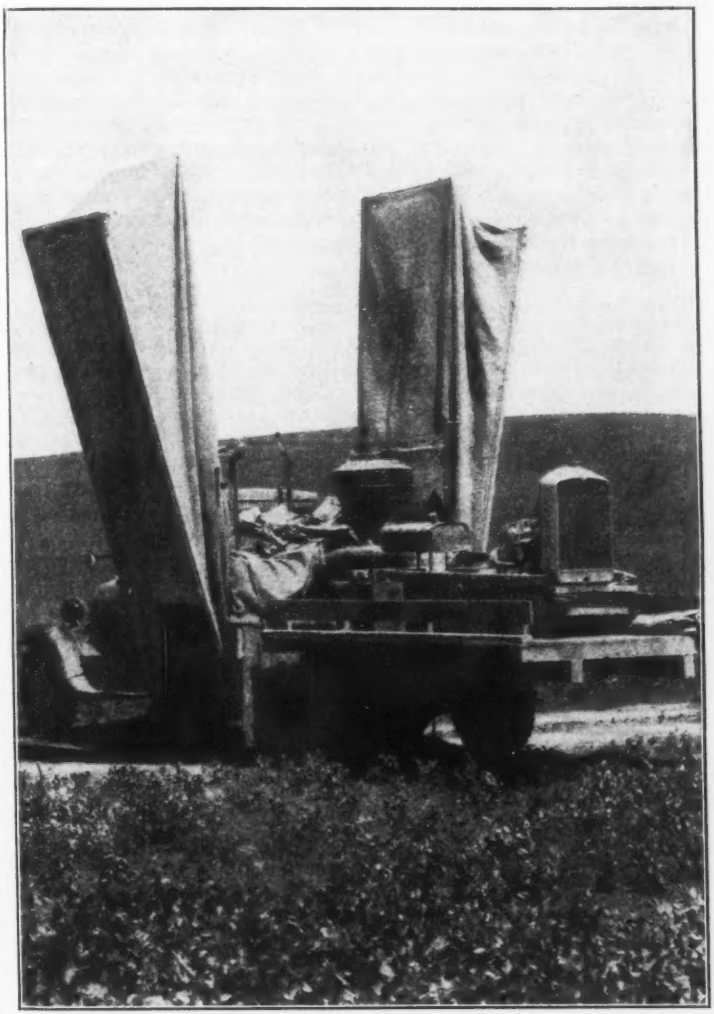

FIGURE 24.—Duster used in pea weevil control in the Pacific Northwest. The hoods on this duster have been raised to show their flexibility and construction. When in operation, they extend horizontally and at right angles to the truck. The nozzles are located under the hoods and adjacent to the truck body and blow the dust the full length of the hoods.

The type of duster used most successfully during the 1937 season had hoods 3 to 4 feet high and 4 to 5 feet wide projecting from 15 to 20 feet on each side of a truck or trailer (fig. 24). The length of the hoods,

however, may be varied to meet individual needs. It should be possible to raise or lower the hoods to adjust their height to the height of the peas, and they should be weighted at the bottom with iron rods or some heavy material to prevent whipping by the wind. The hoods should be so constructed that they may be raised to a vertical position or otherwise folded out of the way, and they should be easy to dismantle. When the dust mixture is being applied to border strips only, it should be possible to shut off the dust mixture on one side of the machine. All the dusting equipment should be of the sturdiest construction in order to reduce break-downs, since a difference of even 1 day in time of application of the insecticide may make considerable difference in the degree of control obtained. The use of hooded dusters makes it possible to apply dust mixtures under windy conditions.

Figure 24 shows a duster used in pea-weevil control work during the 1937 crop season. The hoods, attached over the outlet nozzles, have been raised to a vertical position.

APPLY DUST MIXTURES TO GARDEN PEAS TO CONTROL THE PEA WEEVIL

Like those in large-scale operations, the peas in small gardens should be treated with the dust mixture before any pods appear on the vines, and this treatment should be repeated when a careful examination of the vines shows that any weevils are present. The dust mixture should be applied at the rate of approximately 25 pounds per acre or one-fourth of a pound to 100 linear feet of row.

Plant Border Trap Crops

The use of border trap plantings is advocated because in most instances they have served to attract the majority of the weevils to where they can be killed by dusting with the mixture containing rotenone before the main field comes into blossom. The plantings should be one drill wide (10 feet) and should be sown so that the peas in the strips will blossom from a week to 10 days before blooms appear in the main plantings. It is necessary that the weevils in these borders be destroyed by applying the insecticide before the main crop blossoms. The peas in the borders may become heavily infested later in the season, so the vines should be plowed under or otherwise destroyed as soon as they have gone out of bloom.

Sanitary and Preventive Measures

Sanitary measures to prevent the development and escape of the pea weevil from infested peas are of equal value with the application of dust mixtures containing rotenone as a means of reducing weevil populations from year to year. The most important of these sanitary measures are the following:

PLANT WEEVIL-FREE SEED

Never plant seed containing living weevils. Large numbers of weevils are able to escape from such seeds and infest the growing crop.

DO NOT GROW SEED PEAS IN CANNING AND GREEN-PEA DISTRICTS

Peas allowed to ripen for seed in canning-pea areas are the primary source of pea weevil infestations. Salvaging overripe canning peas as seed only breeds more weevils to infest succeeding crops. The

development of the pea weevil can proceed without interruption in dry peas, and since the harvest loss in these peas is often extremely heavy, large numbers of weevils are able to complete their development. The production of seed peas also leads to the presence of many volunteer peas, in which additional pea weevils may breed and develop.

TAKE CARE OF VINER REFUSE

At the viner there is also a loss of peas in which pea weevils can complete their development. The best practice for weevil destruction and maintenance of soil fertility is to return to the land and immediately plow under all viner refuse. This material may also be stacked as ensilage for livestock. Few weevils escape from stacked viner refuse, since it decomposes rapidly. On the other hand, the insect is able to develop readily in refuse allowed to dry for hay.

PLOW UNDER FIELD REFUSE

The peas left on the field after the green pea crop is harvested can serve as a source of continued infestation. The most effective way now known to handle this refuse is to plow deeply immediately after harvest. Peas grown as a soil-conservation crop should be thoroughly plowed under shortly after they blossom; otherwise they constitute a distinct source of weevil infestation for all the peas in the area about them.

DESTROY THE VINES IN HOME GARDENS

Peas allowed to ripen in home gardens are a source of weevil infestation. Garden plantings should be periodically dusted with a dust mixture containing rotenone, and as soon as the peas get beyond the edible stage the vines should be destroyed.

CLEAN UP POSSIBLE HIBERNATING QUARTERS

The most severe damage in infested localities and on individual farms usually occurs where the peas are grown near good hibernating cover. Many places favorable for hibernation, such as brush-filled fence rows, can be cleaned up, and others, such as isolated trees, abandoned orchards, and dilapidated fences and farm buildings, can be readily removed. The value of such preventive measures varies with the number of favorable hibernating places near the peafields. Clean-up measures will be more effective in fields situated some distance from extensive timbered or brushy areas than in fields immediately adjacent to such areas.

IN PEAS GROWN FOR SEED

Plant Weevil-Free Seed

Much weevil-infested seed is planted with the thought that the insects will not be able to emerge from the seeds. Such is not the case, however, for experimental work has shown that large numbers of such weevils are able to escape.

Harvest Seed Peas Before Weevil Emergence Takes Place

Observations have shown that seed peas ripen and are ready for harvesting some time before the pea weevil is ready to emerge. All peas, therefore, can and should be harvested before emergence takes place. Usually it is profitable to harvest the peas as soon as they are ripe, in order to eliminate loss due to the shattering of overripe peas. Moreover, the fewer shattered off in the field, the fewer weevily peas left to increase infestation the following year.

Prevent Harvest Loss

The pea weevil problem in the Northwest starts with the peas lost during the harvesting process, for if all the peas were harvested before weevil emergence started and no weevil-infested seeds were lost on the ground or left unharvested, no weevils would survive to attack succeeding crops.

Harvest loss cannot be eliminated completely, but field counts indicate that the loss varies with the care used in harvesting the peas. Few peas are lost by an efficiently operated combine, but if the same machine is in the hands of a careless operator it can produce quite the opposite results.

Plowing under the shattered peas to a depth of 8 inches immediately after harvest has thus far proved the most effective method for destroying the weevils in peas lost during the harvesting process. Pasturing the fields, especially with sheep, results in the consumption of many weevil-infested peas. Such a practice is very beneficial if the pasturing is done before weevil emergence has started.

Apply a Dust Mixture

The application of dust mixtures having a rotenone content of 0.75 percent has also given beneficial results when applied to peas grown for seed. The same procedure as outlined for cannery peas should be followed in treating peas grown for seed.

Treat Seed

As soon as the peas are ripe they should be harvested into tight bags. This procedure reduces harvest loss, prevents the escape of weevils from the peas before they are harvested, and makes it impossible for the weevils to escape from the bags after harvest. Bags of peas containing living weevils should be fumigated, by methods described later in this bulletin, or otherwise treated to prevent the escape of weevils during the cleaning or milling process.

Austrian winter field peas should be fumigated immediately after harvest in order to kill any pea weevil larvae that may be present before these develop sufficiently to affect the germination of the seed.

CONTROL OF THE BROADBEAN WEEVIL

The general methods of control recommended for the pea weevil are also of value against the broadbean weevil, since the latter species does not attack the dry seed and has only one generation each year. As insecticides containing rotenone have not been tested against the broadbean weevil, no information is available regarding the possible

effectiveness of this method. In the control of the broadbean weevil particular attention should be given to the following points:

(1) Plant only weevil-free seed or seed that has been fumigated by methods described later or otherwise treated to kill all contained weevils.

(2) Infested seed that has not been fumigated or otherwise treated to kill the weevils should be kept in tight receptacles until the second year, by which time the infesting weevils will be dead.

(3) Infested seed that has not been treated to kill the weevils and cannot be kept in tight receptacles should be fed or otherwise disposed of before the planting season.

(4) Badly infested seed should be ground up in feed mills as soon as it is harvested.

(5) Planting of broadbeans in localities known to be infested by the weevil should be delayed until as late as possible, preferably after March 1 under California conditions. In the dryer and hotter localities where delayed planting is not possible, it is especially important to plant only weevil-free seed.

CONTROL OF THE LENTIL WEEVIL

Although no opportunity has been afforded to perform experiments on the control of the lentil weevil, it is believed that the control recommendations suggested for the pea weevil should be effective against the lentil weevil, since the habits of these two species are similar.

CONTROL OF THE BEAN WEEVIL AND THE SOUTHERN COWPEA WEEVIL

There are two distinct problems in the control of the bean weevil and the southern cowpea weevil, since these two species of weevils attack the crop not only in the field but also in storage.

The problem of control in the field can be solved by eliminating, prior to planting time or at least early in the growing season, all small or large lots of dried beans, cowpeas, and bean or cowpea straw on the farms and in the warehouses that serve as breeding places during the summer or crop-growing season. Danger from these sources may be eliminated by proper fumigation of the seeds by methods discussed later in this bulletin or by feeding the material to livestock or otherwise disposing of it. The only practical method of eliminating straw containing infested beans or cowpeas is to use it for feed or plow it under deeply and cleanly or burn it. The cleaning up of sources of infestation must be done thoroughly and efficiently by every person in a bean-growing community if satisfactory results are to be obtained. If a few sources of infestation are neglected, these may supply a sufficient number of weevils to infest an entire bean-growing district.

The control of the bean weevil and the southern cowpea weevil in the warehouse or other storage quarters depends on frequent and thorough examination of all beans or cowpeas stored therein, followed by efficient fumigation when necessary. The floors and cleaning machinery of weevil-infested warehouses should be kept free from beans or cowpeas, and general sanitary measures should be instituted to clean up all possible sources of weevil infestation.

CONTROL OF THE COWPEA WEEVIL AND THE MEXICAN BEAN WEEVIL

The general control methods suggested for the bean weevil and southern cowpea weevil should be followed in combating the cowpea weevil and the Mexican bean weevil.

FUMIGATION

All species of weevils mentioned in this bulletin may be killed in storage by fumigation with any one of several materials, including carbon disulfide, carbon tetrachloride, an ethylene oxide-carbon dioxide mixture, hydrocyanic acid gas, and chloropicrin.

CARBON DISULFIDE

Fumigation with carbon disulfide (CS_2) is one of the simplest remedies for weevils. **However, the main drawback to the use of this material is its inflammability and explosiveness when mixed with air.** Carbon disulfide is available as a liquid and is sold in iron drums or tin cans. Upon exposure to air, the liquid evaporates or volatilizes, forming a foul-smelling gas that is about twice as heavy as air. Because the gas is heavier than air and evaporates more quickly if a larger surface of the liquid is exposed to the air, the liquid should be poured out into shallow pie tins or similar shallow dishes and placed upon the top of the seeds to be fumigated. Seeds will not be injured or poisoned if the liquid is sprinkled or poured directly upon them. In estimating the quantity of carbon disulfide needed, the total cubic space in the container in which the fumigation is done should always be considered—not just the amount of space occupied by the seeds.

If used according to directions, carbon disulfide will not injure the germination of thoroughly dry seeds or affect their value for food. The disagreeable odor passes away after the fumigated seeds have been aired.

Seeds to be fumigated should be placed in an airtight container. This may be a tin pail, wash boiler, barrel lined with heavy paper, galvanized-iron garbage can, or other receptacle, or a specially constructed fumigation box or room, according to the quantity of seed to be fumigated. One of the simplest satisfactory containers for fumigation on a small scale is a watertight barrel. The tighter the receptacle, the better the results. Satisfactory results cannot be secured if fumigation is attempted in a container or room full of cracks.

Carbon disulfide should be used at the rate of from 4 to 10 pounds to each 1,000 cubic feet of space to be fumigated, the quantity to be used varying with the tightness of the container and the temperature. The liquid quickly vaporizes, and as the gas is heavier than air, it sinks to the bottom of the container, filling all the air spaces. Fumigation should continue from 24 to 48 hours, although most of the actual killing is done during the first 6 to 8 hours of exposure. It is always better to use too much rather than too little carbon disulfide.

Beans, cowpeas, and peas can be stored and fumigated conveniently in watertight barrels. These should be filled to within a few inches of the top with seeds. In fumigating, pour one-half cup or more of carbon disulfide on the seeds and then cover the top of the barrel

with a double thickness of heavy wrapping paper tied tight around the top, or several sacks weighted down with boards. A wooden cover is also useful in keeping in the fumes.

To give the best results, fumigation with carbon disulfide should be carried on at or above a temperature of 75° F. It is not effective at temperatures below 60°. After fumigation the seeds should be examined occasionally and given a second or third fumigation in case living weevils are found.

Carbon disulfide costs from 6 to 25 cents a pound. It is cheapest when purchased in 55-gallon drums (550 pounds). The cost is greatest when the liquid is bought in 1-pound cans, when the price may range from 25 to 40 cents per pound.

To these prices must be added transportation costs. Farmers throughout the country can purchase carbon disulfide at local drug stores, but prices under such conditions often are exorbitant. County agents, boards of trade, or other public-spirited local organizations can purchase carbon disulfide and furnish it at cost to farmers in the vicinity. This has been done in certain southern towns with the result that farmers have secured carbon disulfide of excellent quality at lowest price.

PRECAUTIONS THAT MUST BE OBSERVED IN USING CARBON DISULFIDE

While carbon disulfide has become a standard fumigant and has been used for years without trouble by many individuals and firms, the fact must be emphasized that carbon disulfide is a highly inflammable liquid that will give off, at a temperature as low as −22° F., vapors that will explode if present in the air in from 1 to 50 parts in 100, if they come into contact with fire, sparks, or even hot metal.

The vapors can be ignited by any kind of flame, such as a lighted lantern, sparks from electric switches, or lighted smoking materials. Hot steam pipes, a heavy blow such as may be struck by a hammer, or even heating grain where the temperature rises as high as 212° F., may cause the vapor-and-air mixture to explode. The vapors are heavier than air and may flow along the floor a considerable distance to a source of ignition and flash back to cause an explosion.

From a fire and explosion standpoint, carbon disulfide is much more dangerous than gasoline.

Because of the fire hazard involved in the use of carbon disulfide, most insurance companies prohibit its use in buildings covered by their policies, except in certain cases where its use is permitted under conditions imposed by the companies.

The following permit for the use of carbon disulfide as a fumigant is endorsed by the Southeastern Underwriters' Association and the Virginia Insurance Rating Bureau:

CARBON DISULFIDE

(Permit for Use of as a Fumigant)

In consideration of the following warranties, permission is hereby granted for the keeping on premises and for the use of carbon disulfide as a fumigant or insecticide.

Warranted by the assured:

1. That not exceeding one pound of carbon disulfide for each 100 cubic feet, interior space, will be used in the fumigation of any building or compartment.

2. That all carbon disulfide, on storage, will be kept in metal, preferably zinc lined and sealed receptacles; and that these receptacles will be kept detached at least 50 feet from all main buildings, or buildings where open fires or lights are maintained.

3. That no open fires or lights will be allowed in any building subject to fumigation with carbon disulfide.

4. That all electric and telephone wires entering any building subject to fumigation with carbon disulphide will be equipped with outside control switches, enclosed with lock boxes, and that these switches will be opened and locked during the entire period of fumigation.

5. That no artificial heat of any description will be allowed in any building or compartment subject to fumigation during the period of fumigation.

6. That any or all buildings or compartments which are under fumigation will remain closed for a period of at least twenty-four hours, and when opened, following fumigation, will be thoroughly ventilated for a period of at least three hours before being used.

7. That when fumigated, all doors of the building or compartment shall be locked and the keys turned over to one reliable and responsible person in charge.

CARBON TETRACHLORIDE

Carbon tetrachloride (CCl_4) is a fumigant that has been used as a substitute for carbon disulfide in fumigation work, since it has the advantage over carbon disulfide of being noninflammable. When pure, carbon tetrachloride is a thin, transparent, colorless liquid, with a pungent, aromatic odor. Except for being noninflammable, it is similar to carbon disulfide in all essential features, from the standpoint of application. It costs from about 5.8 cents per pound in large quantities to 10 cents per pound in small quantities. It is not likely to take the place of carbon disulfide because of its inferior killing qualities. Its great advantage is its noninflammability.

If carbon disulfide or carbon tetrachloride cannot be secured from local firms, the names of firms supplying these chemicals may be obtained from the Bureau of Entomology and Plant Quarantine, United States Department of Agriculture.

ETHYLENE OXIDE-CARBON DIOXIDE MIXTURE

The ethylene oxide-carbon dioxide mixture is composed of one part of ethylene oxide and nine parts of carbon dioxide by weight. It is a noninflammable, nonexplosive gas and is not highly toxic to man. For these reasons this fumigant may often be used where insurance regulations or other restrictions prevent the use of other fumigants. The gas is sold in cylinders under pressure and is adapted chiefly for use in fumigating chambers. Moreover, it has the advantage of not leaving any appreciable odor in the fumigated product.

The ethylene oxide-carbon dioxide mixture should be used at the rate of 20 pounds per 1,000 cubic feet under average conditions, with suitable changes in this dosage according to the airtightness of the fumigating chamber. The period of fumigation should be the same as for carbon disulfide, and the room should be at a temperature not lower than 60° F.

The cost of this fumigant ranges from approximately 14½ to 16 cents a pound delivered.

Caution.—The ethylene oxide-carbon dioxide mixture should not be used to fumigate peas, beans, or other seeds intended for planting purposes, since this gas ordinarily injures the germination of such seed.

CHLOROPICRIN

Chloropicrin, one of the tear gases used in the World War, is now utilized to some extent in fumigating peas infested by the pea weevil. It possesses the advantage of being noninflammable and of costing less than some of the other fumigants, and it has given effective results when used according to directions.

Although this gas is a deadly poison, it has a disagreeable and irritating effect upon the eyes and the respiratory passages that prevents people from entering buildings or other structures where there are dangerous concentrations of chloropicrin. Moreover, the fumigated seeds must be thoroughly ventilated or air-washed before they can be handled, because traces of chloropicrin gas may be retained in the fumigated product for several days. When this gas is used in fumigating, 1 pint (or 1.7 pounds) of chloropicrin should be used for each

FIGURE 25.—Carload lots of 240-pound sacks of chickpeas as stacked in a badly infested warehouse. Samples taken throughout the length of the sack proved that the hydrocyanic acid gas had penetrated to the very center and that the infestations were all killed.

1,000 cubic feet of space. The treatment should continue for at least 36 hours, and it is most effective at or above a temperature of 75° F. It is not effective at temperatures below 60°.

To apply this fumigant sprinkle it on pieces of burlap sacking or pour it into shallow evaporating pans. A gas mask is essential if large quantities of chloropicrin are to be used.

Chloropicrin costs approximately $1.35 per pound, in 100-pound cylinders, exclusive of the cost of transportation.

HYDROCYANIC ACID GAS

Fumigation with hydrocyanic acid gas is recommended when large quantities of beans, peas, cowpeas, or chickpeas are found infested with weevils. The seeds must be in sacks and so stacked that the gas can reach several sides or portions of the sacks. Chickpeas stored in 240-pound sacks, and stacked as shown in figures 25 and 26 were almost perfectly protected by fumigation. It has been found in the

fumigation of warehouses, sometimes as large as 150 by 150 by 20 feet, and containing as many as thirty thousand 240-pound sacks of chickpeas, that hydrocyanic acid gas can be depended upon to eliminate infestations almost completely. Fumigation with this gas for the control of bean and pea weevils has proved so satisfactory that its use is now an established practice with certain firms. For seed so stored the dosage should be increased from the normal dosage of 1 pound of sodium cyanide for each 1,000 cubic feet of space to be fumigated to 2½ pounds per 1,000 cubic feet. Since it is extremely poisonous, hydrocyanic acid gas should be used only by responsible persons who are thoroughly informed on the subject of fumigation. As the gas is lighter than air and readily escapes, does not injure the seeds for planting or for food, injures no warehouse equipment, and is non-

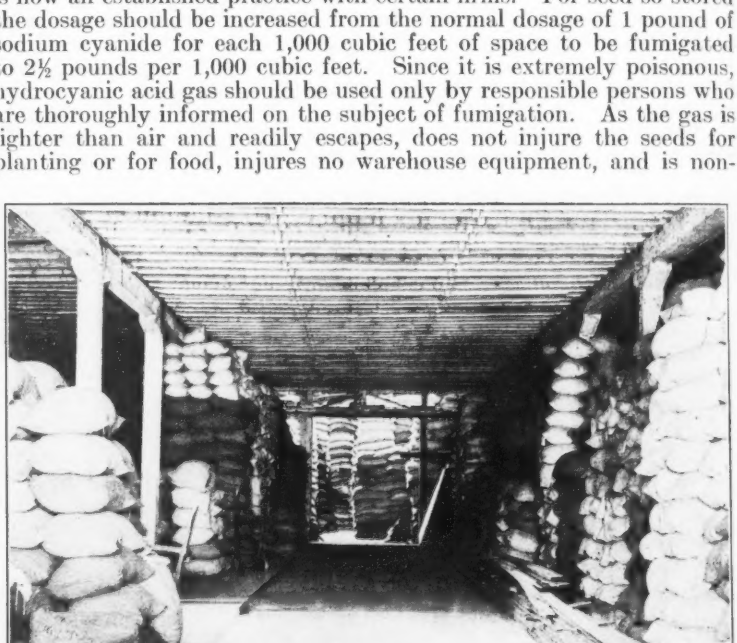

FIGURE 26.—Interior view of a warehouse containing 30,000 240-pound sacks of chickpeas having a retail value of $864,000 at the time of treatment. Infestations breaking out under such abnormal storage conditions were controlled by fumigation with a hydrocyanic acid gas.

inflammable when mixed with air in the proportions used in fumigation, it lends itself to use in almost any warehouse section if the fumigation is properly timed and supervised. More detailed discussion of the use of hydrocyanic acid gas as a fumigant is given in Farmers' Bulletin 1483 and Circular 369.

HEAT

Heat as a means of killing weevils in legumes is growing in favor. Small quantities of seed grown on the farm or in the town garden can be treated by placing them in an oven after they have been spread rather thinly in shallow pans and heating them to from 120° to 145° F. for several hours. An old remedy is to dip seeds into boiling water for 1 minute. Holding seeds in boiling water for more than 1 minute will injure their value for planting purposes, and immersion for even

1 minute has been known to affect germination. On removal they should be spread out immediately and dried rapidly.

Weevil development in large quantities of beans, peas, and cowpeas can be stopped by a process known as kilndrying. This process consists in heating the seeds to a temperature of 120° to 145° F., or higher, while they are being passed through a machine called a drier. This treatment not only removes a portion of the moisture in the seeds but also kills all insects in them. The loss of moisture may be an item of importance if sales are made by the pound, yet investigators claim that seeds containing 20 percent of moisture or less are not easily infested by weevils, hence excessive drying with the heat not only kills the weevils but renders seeds less susceptible to reinfestation.

The embryos of the bean weevil are killed when exposed to a temperature of 125.6° F. for 10 minutes; the newly hatched larvae die in 7 minutes at 131°; full-grown larvae in beans die in 20 minutes at 131°; and pupae die in beans when exposed for 25 minutes at 131°. Adults are killed by a 4-minute exposure at 131°. These data cannot be relied upon when large masses of seed are to be treated. It was found that 9 hours were required for the center of 2 quarts of beans inclosed in a tight paper bag to reach the surrounding temperature of 131°. Cowpeas infested with the southern cowpea weevil were not absolutely freed from insect infestation when exposed to 140° for 5 minutes, though all the weevils were killed when the seeds were exposed to this temperature for 10 minutes in an oven. These results in killing the southern cowpea weevil were secured under conditions more favorable than those likely to occur in commercial bean establishments, hence it is recommended that seeds be exposed in commercial treatment to 146° for 20 to 30 minutes. Temperatures above 150° seemed to weaken the resulting plants, but germination took place even after the seeds had been subjected to 190° for 10 minutes. Commercial coffee roasters are used by certain bean brokers for the destruction of weevils by heat. Seeds have been treated by the carload in such roasters and were guaranteed to remain free from injury by bean weevils at least during transit in carload lots. A list of firms that manufacture apparatus for heating seeds will be furnished upon application. As in kilndrying, the seed should be spread out in order that all may be affected quickly and uniformly by the heat. When they are thus spread out, an exposure to 131° for 1 hour should be sufficient.

Heat is not recommended for the control of the broadbean weevil in broad or Windsor beans. Exposure to temperatures ranging from 120° to 140° for 5 to 40 minutes did not kill this apparently more hardy insect, and the higher temperatures had an injurious effect upon germination.

COLD AND COLD STORAGE

Weevils will not feed and cause damage at low temperatures. It is not known at what temperature development ceases, but no development takes place at or below 50° F. Cowpeas can be kept free from weevils if held in storage at a temperature of 32° to 34°. It is claimed that exposure for a season at this temperature does not affect the germinating power of the seed. Investigations conducted in this

Bureau indicate that no stage of the common bean weevil can withstand 56 days of cold storage at 31° to 32°, although they may survive more than 66 days at 36°. The larvae, it appears, succumb to cold-storage temperatures more readily than do pupae or adults. The storage room should be kept as dry as possible, and the seeds should be handled in sacks as in warehouses. Cowpeas held for a season at 32° to 34° were found to lose their germinating power no sooner on removal to normal temperatures than cowpeas not thus exposed to cold. Seeds removed from cold storage to warm temperatures are likely to sweat, and if care is not taken to eliminate this surface moisture by drying or proper ventilation, moldiness may result. There is some doubt as to the real need of incurring the expense of cold storage, as seeds can be protected more cheaply by fumigation under storage conditions thought by the majority of seed owners to be better for the seeds.

LIME OR DUST AS A PROTECTION TO SEED

In the Southern States, where weevils cause such great injury to stored seeds, certain farmers have resorted to mixing their seed cowpeas with dry road dust or air-slaked lime. Tests prove that the storage of cowpeas with air-slaked lime at the rate of 1 part by weight of lime to 6 to 8 parts of peas is a great help in protecting seeds. The dust or lime does not necessarily kill the weevil grubs developing in the seeds if these are already in the seeds at harvest-time, but it prevents adult weevils either from emerging, or, if they succeed in emerging, from laying their eggs on the seeds for successive generations. The dust or lime, in other words, prevents continued breeding in storage. Either substance would probably be a nuisance if mixed with cowpeas intended for food if the seeds contained many emergence holes, as the lime or dust would work into these holes and be difficult to remove. If seeds are known to be free from weevils and are stored in tight barrels, bins, or other similar containers, a top layer of air-slaked lime about one-half to 1 inch thick, if maintained, will prevent weevils from gaining access from without and starting an infestation.

COMMUNITY EFFORT TOWARD CONTROL

Anyone can protect beans and peas from further weevil injury after they are once dried and in storage. If loss occurs in storage, owners have only themselves to blame, for weevils can be effectively controlled at a cost very slight as compared with the value of the seeds protected and the increased value of the seeds after thorough treatment.

But no one person can prevent his beans and peas from becoming infested while they are developing in the garden or field unless he and his neighbors are willing to get together and pledge to treat their seeds in storage and to destroy other breeding places, such as bean-straw piles. Many adult weevils fly to fields from storage bins about the time the seeds are beginning to mature. A negligent neighbor may be the cause of much neighborhood infestation by the flying of his weevils to developing crops or into warehouses.

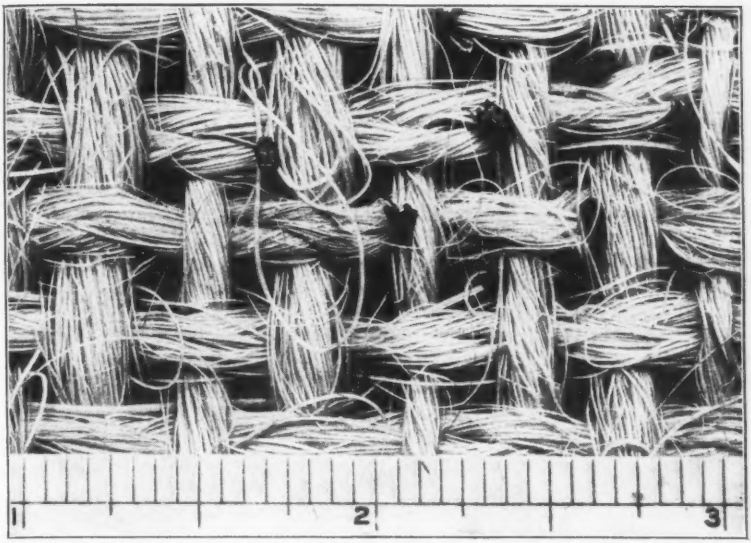

FIGURE 27.—Section of jute sack having about four strands to the inch. Such sacks are of no value in preventing the spread of infestations from sack to sack in warehouses. The adult weevils can leave or enter such sacks at will.

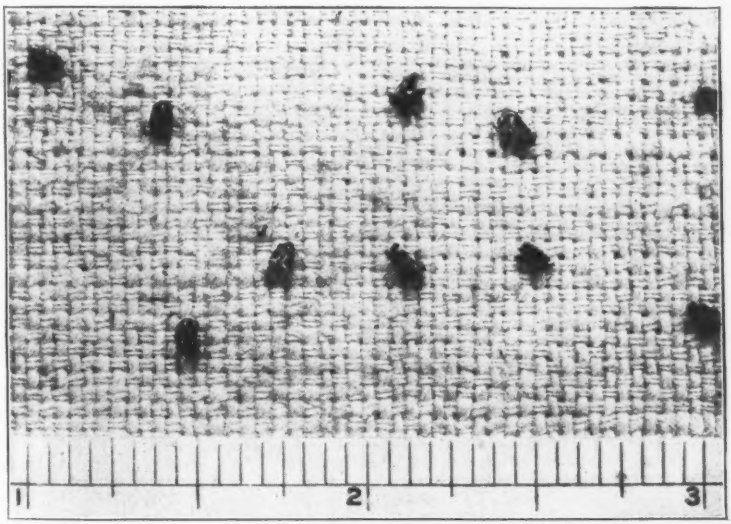

FIGURE 28.—A heavy cotton close-woven sack with about 21 strands to the inch. Sacks made of this material are on the market and have proved their effectiveness not only in preventing weevils from leaving the sacks but also in protecting uninfested seeds from infestation from without.

Community effort to reduce weevil losses can be made effective in localities where beans and peas are grown on a commercial scale. It is doubtful whether concerted action can be secured in towns or cities, where there are many small gardens yielding but a few seeds, for these small quantities of seed are of too little value to move their owners to action. The University of California during 1918–20 conducted a campaign of community effort, in San Mateo County, Calif., directed against the broad bean weevil and found that by working through the county agent and fumigating the crops after they were placed in storage the infestation in the field was reduced from 43 percent in 1918 to 21 percent in 1919 and 17.8 percent in 1920.

Similar community campaigns are being conducted in other regions for the control of the bean weevil and the southern cowpea weevil. The county agricultural agent has here a worth-while field for action along with his many others. To succeed, all farmers in a district should treat their seeds and dispose of all refuse and bean straw before the next bean crop approaches maturity.

REINFESTATION NOT PREVENTED BY TREATMENT

Treatment of legumes subject to infestation by weevils that can breed generation after generation in storage will not keep them free from weevils if they are stored so that adult weevils can get to them and lay eggs on them. The application of remedial measures may kill all weevils in the seed at the time of treatment, but it should be remembered that no treatment has a lasting effect in preventing reinfestation from outside sources. Seeds once treated should be stored in rooms free from adult weevils or placed in tight barrels or sacks made of closely woven material and should be examined occasionally as a guard against subsequent infestation.

When large quantities of seeds are brought together under one roof, they usually represent the crops of many farmers whose local conditions may have varied to such an extent that one carload lot of seed may be free of infestation while the next may be slightly or heavily infested. Experimental work has proved that sacking seeds in one thickness of lightweight close-weave muslin will prevent uninfested seed from becoming infested even though there are many weevils and weevily seeds close by. It is not practical in large seed warehouses to use sacks of lightweight muslin; yet a study in 1917–18 of conditions in large warehouses containing many carload lots of seed indicates the value of closely woven sacks. Jute sacks with but four strands to the inch (fig. 27) are no protection to the seeds within the sack and do not prevent weevils developing in the sacks from crawling out and migrating to and laying their eggs upon seeds in other sacks of similar weave. But seeds sacked in heavy cotton sacks of close weave with 24 strands to the inch are apparently perfectly protected from infestation from without (fig. 28). Some such sacks contained badly damaged and heating seed, but the infestation was held within them and prevented from spreading to adjoining sacks by the tightness of the sacks. The bean weevil and the southern cowpea weevil can eat holes in paper sacks and escape, but do not eat through cloth. There is a great deal in favor of a tight cloth sack, not only for protecting uninfested seeds from infestation from outside sources but also in preventing infestations from spreading.

WHERE TO OBTAIN INSECTICIDES

Information regarding the purchase of the insecticide materials mentioned in this bulletin may usually be obtained through local dealers in agricultural supplies, seedsmen, general stores, drug stores, and department stores, or it may be secured from the county agricultural agent, State agricultural experiment station, State agricultural college, State department of agriculture, or the Bureau of Entomology and Plant Quarantine, United States Department of Agriculture.

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